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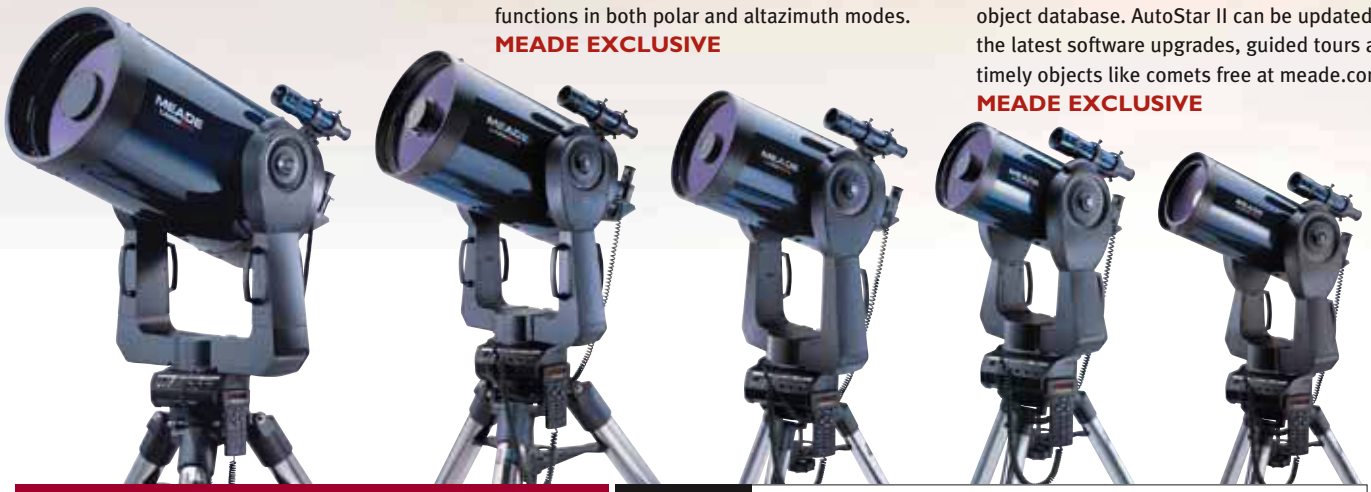

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ON THE COVER

An ancient red star in the Milky Way's halo contains secrets of the universe's earliest days. A new technique, developed by astronomer Timothy Beers of Michigan State University, measures radioactive elements in old Milky Way stars to unlock the age of the galaxy and the universe itself.

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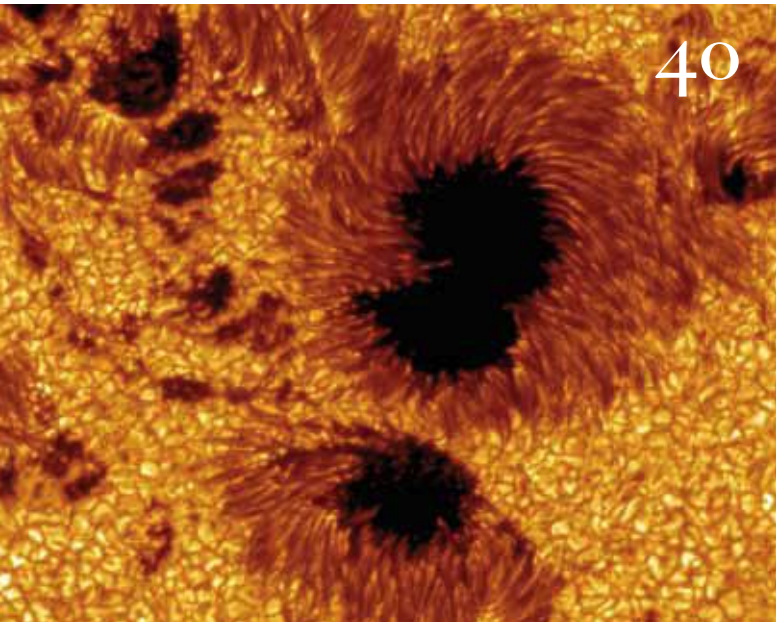

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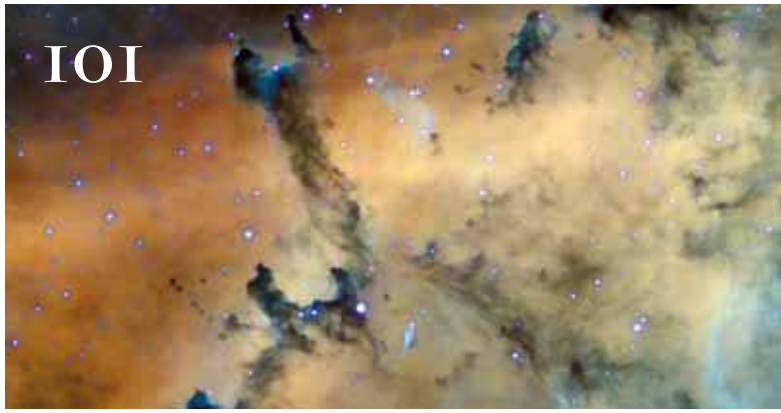

KEN CRAWFORD

BY DAVID J. EICHER

Galaxy clusters heat up

Galaxies congregate in groups, with

the biggest being galaxy clusters. Here, in the urban jungles of the cosmos, survival of the fittest plays out on scales hundreds of thousands of light-years across. Big galaxies, the bullies on the block, gravitationally pull in their neighbors and absorb them. In these hot, violent worlds, the small become lunch.

Until recently, astronomers thought they understood how galaxy clusters form: Clumps of material coalesced by the gravitational force of dark matter, forming the first structures which evolved into galaxies and then clusters of galaxies.

Near a cluster's center, immense pressure crushed material and caused it to glow with the X rays astronomers observe today. Then, the gas inside a cluster cooled, carrying away radiation in the form of heat. Hotter gas flowed into the cluster's center, filling a void, where the cycle of compression, radiation, and cooling started again.

This so-called cooling-flow model was gospel in astrophysics until recently. Now, however, as Steve Nadis writes in "The hot, violent world of galaxy clusters" (p. 34), astronomers are finding the picture is changing. Paul Nulsen of the Harvard-Smithsonian Center for Astrophysics was one of the authors of the original cooling-flow model. "Now we think it's almost completely wrong," he says.

Nadis describes a more complex picture of heating and cooling that may explain the origins of galaxy clusters. New data from the orbiting Chandra X-ray Observatory is altering the scenario and painting a fascinating picture of the early universe — a time when many galaxy clusters formed.

This story is an example of how astronomers studying one aspect of a problem (gas flows) ingeniously deduced unexpected conclusions from it — a snapshot of how everyday science works. Don't miss the simulations of cluster flows on our web site, www.astronomy.com.

In another story, Nadis tells how astronomers are using Milky Way stars to probe the universe's early history. In "Neighborhood secrets" (p. 46), Nadis describes a brand-new field: doing cosmology with stars. Michigan State University astronomer Timothy Beers is a pioneer in this effort. Beers focuses on old stars in the Milky Way's halo; stars removed from the active, star-forming regions in the disk.

Beers then examines the abundance of certain elements in halo stars. This tells him not only about the nature of the earliest stars, but of the environments that gave birth to them, and the products of the earliest supernovae that ended their lives.

The indicators Beers uses are thorium and uranium. These radioactive elements decay at known rates and, thus, can be used the same way carbon-14 dating is employed on Earth. The astronomical equivalent is applied to stars billions of years old and thousands of light-years away. The technique may pin down the age and early composition of the galaxy and, ultimately, of the universe itself.

Yours truly,

David J. Eicher
Editor

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Focal Length	2000mm	2500mm	3048mm
Smart Drive™ (PPEC)	Included	sn uded	Included
LX-Series Field Tripod	Included	Included	Included
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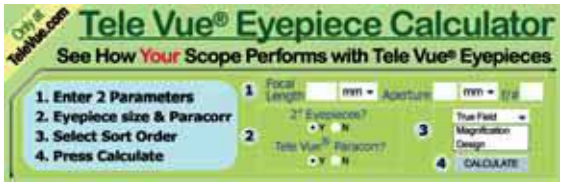

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Hunting space rocks

While I enjoyed David Healy's "Join the hunt for space rocks" (March 2005), I hope people aren't misled into believing they are going to hook a camera to a telescope and quickly discover an asteroid or comet. The extensive LINEAR program has managed to sweep up most bright asteroids and comets. At Farpoint Observatory in Eskridge, Kansas, we search for minor planets. A look at our discovery rate illustrates how the chance of finding new objects has diminished: We found 93 designations in 1990, 82 in 2000, 101 in 2001, 53 in 2002, 6 in 2003, and 7 in 2004. In 2004, we shifted our emphasis to near-Earth object (NEO) follow-up activities.

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THE LINEAR PROGRAM has implemented technology previously used for monitoring Earth-orbiting satellites into the hunt for NEOs. Since 1997, LINEAR has discovered more than 1,600 NEOs.

If you want to get involved with asteroid imaging and astrometry, my recommendation is to assist in NEO research by getting astrometry of newly discovered objects.

If your equipment can reach magnitude 20, you should be able to contribute significantly to the NEO work. And who knows, you might chance upon that new asteroid or comet. To get started, visit *cfa-www.harvard.edu/iau/mpc.html*.

— GRAHAM BELL, MAPLE HILL, KANSAS

Coyne of the realm

I enjoyed reading Father George Coyne's comments regarding conflicts between science and religion (March 2005). It is telling that a theologian and scientist like Coyne believes contradiction isn't the problem, but ignorance. He certainly holds authority from both points of view.

— HAROLD ALLEN, NEW BRUNSWICK, NEW JERSEY

I appreciate that Father George Coyne shared his thoughts concerning theology and science, but I am disappointed that he didn't touch on or explain the Vatican's point of view.

The Vatican has embraced astronomy and what we have learned about the universe. Yet, Coyne never commented beyond his personal beliefs.

A keen point found in the interview is that the administration in Rome takes minimal interest in the scientific aspect of what Coyne and his fellow researchers do at the Vatican Advanced Technology Telescope near Safford, Arizona.

Perhaps greater understanding between scientists and theologians could be reached if the Vatican took a more active role in scientific research beyond funding.

— THOMAS WHISTLER, GADSDEN, ALABAMA

After reading Father Coyne's comments, I realized how far the Catholic Church has come with its view of astronomy since the time of Galileo. — RICHARD FRANKLIN, BROOKLYN PARK, MINNESOTA

Time to relocate

Ian Ridpath's "Explore the spring sky" (March 2005) should have profiled the deep-sky treasures found in the Southern Hemisphere sky during this time of year. I'm sure it would make some of your readers consider relocating. — RHYS CLARKE, NEWCASTLE, AUSTRALIA

Fortunate meeting

I had the pleasure of meeting Neil deGrasse Tyson at the Hayden Planetarium in New York City. Although it was a brief encounter, I was overwhelmed by his insight and thoughtfulness. I believe your interview with him (March 2005) gave a glimpse of his character. What a champion for astronomy! — CAROL MABAREK, NEW YORK CITY

Correction

In the February article "Relativity turns 100," the falling rock's path in the second diagram on page 34 should have followed a parabola. Thanks to the sharp-eyed readers who spotted the error. — *ASTRONOMY* EDITORS

We welcome your comments. Send letters to Astronomy *Letters, P.O. Box 1612, Waukesha, WI 53187; e-mail: letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

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BY BOB BERMAN

Can't price passion

Some people cough up $65,000 to climb Everest, then shiver for 9 miserable weeks in cramped mountainside tents, hoping to spend a few frozen minutes at the top. We admire them, but we also know they're nuts.

Do backyard astronomers possess that same chromosome, the one that controls masochism? If we added up astronomy's pluses and minuses, would they at least balance out? Such cost-benefit calculations are standard practice in business: Has anyone ever done it for the astronomy hobby?

Witness this hypothetical scene: Bill purchased an ultra-expensive Cassegrain before he got married — his wife would have insisted they buy wallpaper instead. He lives in a suburb of Washington, where the sky is clear one night out of every 36,000. When the sky *is* cloudless, lights from the nearby metropolis limit the nightly naked-eye view to the Moon, four planets, 28 stars, and a passing police car.

So Bill invested in light-pollution filters, which would work better if his semi-insane neighbor hadn't surrounded his home with yard lights that could turn Machu Picchu into Times Square.

Sometimes Bill begs his neighbor to douse the klieg lights for an hour. The neighbor cheerfully agrees — in exchange for Bill cutting down his prized oak, whose overhanging limbs drop leaves into the neighbor's pool. Bill says "OK," figuring it's a small price to pay for astronomy. He'll deal with his wife's reaction later.

Now Bill can haul out his scope — which disassembles into three portable parts weighing only 430 pounds apiece. Bingo, there's the Ring Nebula, accompanied by an audio soundtrack of buzzing mosquitoes and the neighbor's yapping schnauzer. Nowhere in the universe is M57 being viewed in quite this way, except maybe on the planet Melivian 218 — where the mosquitoes play little harmonicas.

Other than herniating his L5 spinal disk while toting the scope back inside, the night has been successful. "I love astronomy!" Bill gushes the next day to his psychotherapist. The shrink totally understands: Studies show that intermittent pleasure provides the maximum incentive to repeat an activity. It's true. A rat will run a maze more often if cheese isn't always at the end of it.

NOWHERE IN THE UNIVERSE is M57 being viewed in quite this way, except maybe on the planet Melivian 218 — where the mosquitoes play little harmonicas.

Part of astronomy's allure is that we have to work at it. The cheese isn't always there. We go to eclipses when half are cloudy. We crave ever-larger scopes even though they are bigger hassles. We buy it anyway, the 10-foot Goliath taking up the living room and changing the home's decoration scheme into "neo-warehouse."

If the new garganto-scope costs $5,000 and we haul it out 25 times in the years to come, we've paid $200 per use. If we gaze at 10 objects each time, it's $20 per nebula, $20 for each galaxy. Figure about $5 a minute. Imagine if it cost $5 a minute to rent a movie. Would anyone do it?

Well, it *must* be worth it. Astronomy can be cheap, too: an *Astronomy* subscription, binoculars, maybe a modest scope, nothing too steep. But how to put a price tag on what we get in return?

The pleasure-module can't be specified because backyard astronomers seek enjoyment from many different pursuits:

- Variable-star devotees are thrilled when they notice Algol is dim or Mira is visible.
- Naked-eye observers get a charge when Orion returns each year, or when they travel south and see the Southern Cross.
- Planetary specialists stare at the same thing over and over; the thousandth view of the Cassini division outclasses the Mona Lisa.
- Deep-space people live for an averted-vision glimpse of M51's spiral arms.
- Astroimagers spend days with CCDs and digital tweaking until getting the perfect nebula shot, which they turn into a screensaver.
- Amateur telescope-makers take justified pride in viewing ancient celestial empires through instruments of their own creation. It does not matter that building the scope required a sunless year in solitary confinement in the workshop. ("Who's that pale, funny-looking man coming up from the basement, Mommy?")

Most of us belong in multiple categories, but we share the same pleasures: the sight of Saturn's rings, or M13, or the mountains inside Copernicus casting shadows on the crater's smooth floor. Wow, does that stuff forever bring a smile to our faces, or what?

As for the work, hassle, and cost that lead up to that moment, the answer can be summed up in two words: Who cares? A

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BY GLENN CHAPLE

Good Sun behavior

"I'm going to be the first human to land a spaceship on the Sun," a man boasts to his friends. "But you'll burn up!" they protested. "No I won't," he responded. "I'll make the voyage at night." Piloting a spaceship to the Sun would be a pretty dangerous enterprise. Piloting a telescope to our nearest star isn't much safer. A sticker on most telescopes provides an ominous, helpful warning: "CAUTION! VIEWING THE SUN DIRECTLY WITH THIS TELESCOPE MAY CAUSE PERMANENT EYE DAMAGE!"

Words like this would scare away even our intrepid solar astronaut. The good news is you *can* explore the Sun with a telescope, as long as you exercise caution and common sense. The safest and least expensive way to view the Sun is by solar projection — using your telescope to project the Sun's image onto a white cardboard screen. This method allows many to view the Sun at the same time. The common 2.4-inch (60mm) refractor is ideal for solar projection. A large-aperture telescope collects too much sunlight and needs to be "stopped down" with an aperture mask, a cardboard sheet with a 2- to 3-inch circular hole, taped to the front of the tube.

High magnification isn't necessary for a target as big as the Sun — 25x–35x will do the trick. The eyepiece I normally use for solar projection is a 20mm Huygenian. While lacking the sophistication of modern, pricier eyepieces, the Huygenian's simple design — a pair of air-spaced convex lenses — makes it a good choice for solar observing. The sunlight collected and concentrated by a telescope's objective lens or mirror could "cook" the cemented optics of more complex eyepieces. Don't risk a $400 wide-field eyepiece for solar projection.

Don't use the finder scope when aiming your telescope at the Sun — even that little scope collects a blinding amount of sunlight. If you're viewing the Sun with curious onlookers — especially children — leave the lens cap on your finder. Target the Sun by studying your telescope's shadow. When the shadow's as compact as it can get, and you see bright light illuminating the eyepiece, you're on target. Project the Sun's image onto a white cardboard sheet facing the eyepiece about a foot away. The bright circle you see is the Sun's disk. Focus until the circle's edge is sharp.

What if you're going solo or want a detailed view with that $400 wide-field eyepiece? **This is where solar filters come in.** Beware of filters that come with inexpensive telescopes and screw into the eyepiece. Just as concentrated sunlight can cook an expensive eyepiece, it can heat up and shatter such a filter. I shudder when I think of those occasions years ago when I used such a filter to show schoolchildren the Sun!

For direct solar-viewing, you need an aperture filter that attaches to the front of the telescope. It intercepts incoming sunlight, allowing a safe amount to reach the eyepiece. Aperture filters can be pricey — costs run from $50, depending on your scope's size and the filter's quality — but they are well worth the cost.

If you want to compare your view of the Sun with those obtained by professional astronomers, I recommend three web sites: *umbra.nascom.nasa.gov/images/latest.html* (from the scientists of the orbiting SOHO satellite); *www.bbso.njit.edu/cgi-bin/LatestImages* (from the Big Bear Solar Observatory); and *www.spaceweather.com* (Dr. Tony Phillips' web site on the Sun-Earth environment).

Astronomy readers can monitor auroral activity by visiting Astronomy.com's "space weather" page.

Next month: high-tech solar-observing tools for the novice. Clear skies.

/// THE SUN UP CLOSE

Whether observed by projection or through a filter, the Sun is a fascinating sight. Its visible disk, the **photosphere**, appears slightly darker near the edge — a phenomenon known as **limb darkening**. Under steady atmospheric conditions, you'll notice a grainy appearance — **granulation** — to the photosphere. Granulation results from the rise and fall of huge masses of gas on that seething cauldron that is the Sun's surface.

The obvious features are the **sunspots** — relatively cool regions on the photosphere that appear as dark blotches. A large sunspot will have a dark center, the **umbra**, surrounded by a grayish **penumbra**.

It's fun to view the Sun each day and watch sunspots develop, then gradually fade, all the time drifting across the face of the rotating Sun. Bright patches of light — **plages** — often accompany sunspots located near the dark solar limb.

Each day, I view the Sun with anticipation. I'm never quite sure what I'll see. —*G. C.*

CLARE UNDERWOOD

CHAPLE'S SEVENTH-GRADE STUDENTS in Townsend, Massachusetts, learn about Sun behavior during an outdoor lab last winter.

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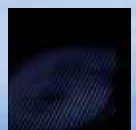

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BY PHIL HARRINGTON

Star clusters close-up

I often receive letters from readers

asking me to recommend a first telescope. Invariably, I recommend binoculars instead. In fact, binoculars may be ideal for viewing the night sky regardless of your level of expertise. They are convenient to use and require no set-up time: Take them out of their case, pull off the eyepiece caps, and you're ready to start observing. What could be easier?

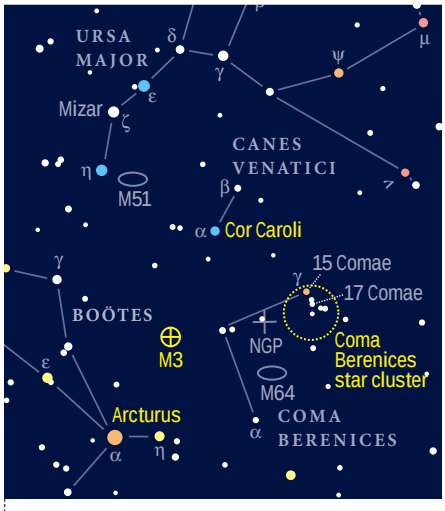
Because we look up with binoculars, rather than down or to the side as with telescopes, binoculars feel more like a natural extension of our eyes. That's why the binocular universe impresses me as a very personal place.

So, welcome to my personal universe. Each month, we will tour that universe together through our binoculars, stopping to enjoy many spectacular sights.

"Arc to Arcturus"

Let's kick off this column with a visit to the bright star **Arcturus** in the constellation **Boötes**. Remember, "arc to Arcturus" by following the curve of the **Big Dipper's** handle. Arcturus is an orange-giant, type-K star. Although larger than our yellow-dwarf Sun, Arcturus has a cooler surface temperature, which is evident by the orangish glint that shows through slightly defocused binoculars. Arcturus lies relatively nearby at 36.7 light-years away, a fact that made it the star of the 1933 Chicago World's Fair. Arcturus was selected because the light that reached Earth in 1933 left the star at about the time as the previous Chicago fair, in 1893.

We can use Arcturus to find other objects of interest in the area. For instance, if you move away from Arcturus toward the west (down and to the right in the evening sky from the Northern Hemisphere) about 4 binocular fields, you come to a dense group of stars. You might even see it as a hazy glow with your eye alone. That's the **Coma Berenices star cluster**, one of my favorite binocular star clusters. This collection of eighty 5th- to 10th-magnitude stars is perfect for 7x to 10x binoculars because it covers 5° of sky — 10 Full Moons can be stacked end-to-end across it.



ASTRONOMY: ROEN KELLY

YOU CAN SEE STAR CLUSTERS EASILY through binoculars. Use this finder chart to locate the Coma cluster.

The cluster is not especially large. Instead, it *looks* large because it lies fairly nearby. Today, we know the Coma star cluster is about 250 light-years away, making it the third closest open cluster to our solar system.

The brightest stars in the Coma star cluster resemble the lower-case Greek letter lambda (λ) or, if you're viewing from south of the equator, gamma (γ). Most shine white, while some may show hints of yellow or orange. For instance, the star marking the top of the lambda, **15 Comae**, is another type-K star, like Arcturus.

Look for **17 Comae**, a prominent double star just east of the cluster's center. Even opera glasses show 17 Comae's primary at 5th-magnitude and its 7th-magnitude companion easily.

Although known as far back as the second century A.D., the Coma star cluster was included in neither the Messier nor the NGC catalogs. It probably was omitted because its large apparent size masks its true nature through telescopes.

A tiny, fuzzy blob

Now, look for the star **Cor Caroli**, the lone star visible to the naked eye just under (south of) the end of the Dipper's handle. Aim your binoculars halfway between Arcturus and Cor Caroli, and then look for a right triangle of three dim stars that points toward the southeast.

Spot it? If so, look at the star marking the right angle. If you look carefully, you'll notice it's not a perfect point of light. Instead, it looks like a tiny, fuzzy "star blob." You're actually seeing a distant globe of more than 100,000 stars — a globular cluster called **M3**. To me, it looks like a distant ball of celestial cotton.

Charles Messier's discovery of M3 May 3, 1764, marked an important point in astronomical history. This accidental sighting, along with his earlier discoveries of a globular cluster in Aquarius and the Crab Nebula in Taurus sparked his interest in compiling his now-famous catalog of 110 deep-sky objects.

Next month, I'll tell the tale of the scorpion's tail. Meanwhile, remember: Two eyes are better than one!

ONLINE EXTRA Get more information on the objects mentioned in this article and read more about spectral types and nearby star clusters at www.astronomy.com/toc

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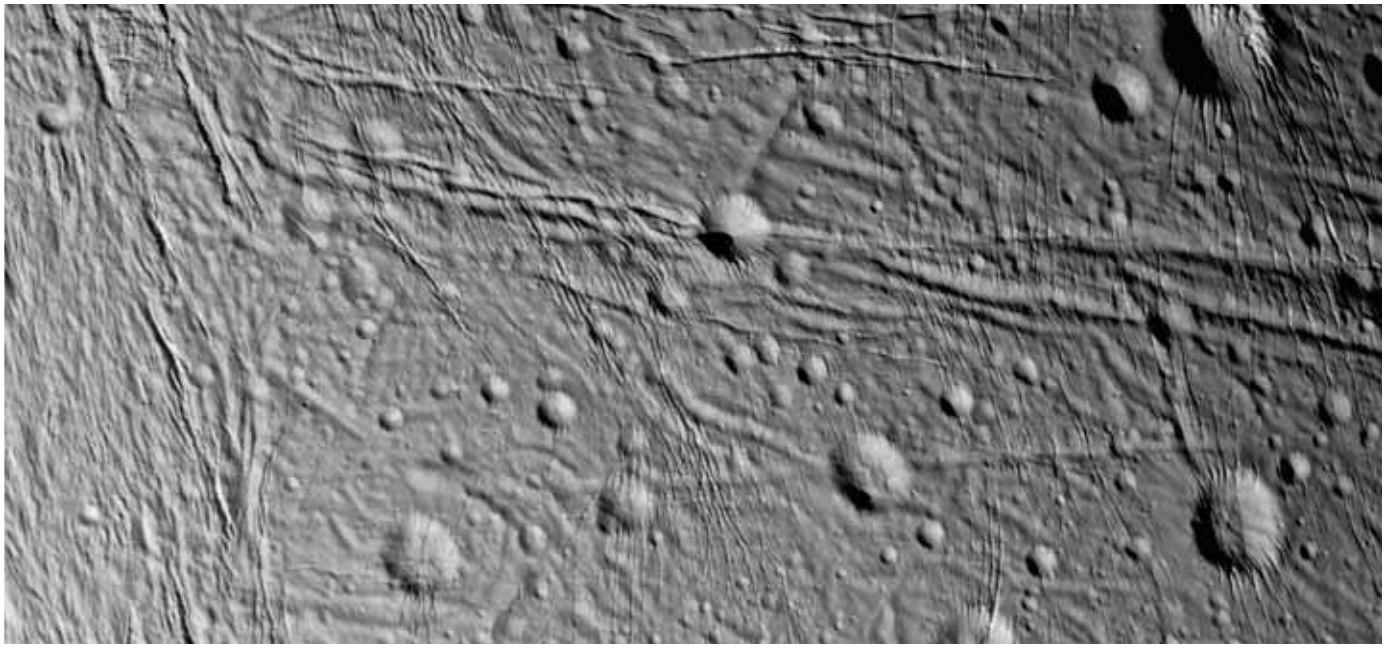
CREEPY GALAXY. Radio astronomers clocked galaxy M33 moving across the sky, the first time such a distant object has had its speed measured directly. The galaxy's velocity was 118 miles (190 kilometers) per second.

news 06

Amazing variety of galaxies in the early universe, how to clean a rover on Mars, a new kind of object at the Milky Way's center, volcanos near the martian north pole, and a pretty little galaxy headed for trouble.



NASA/JPL/SSI

LOOKING CLOSE. Fractures slice Enceladus' face, cutting across craters and other fractures alike while scribing a complex history of impacts and tectonic activity.

24 Watching space shuttles come home

25 Chipping pieces off Mars

28 X rays from a newborn star in the crib

30 How to keep a star's weight under control

Icy Enceladus wrapped in water vapor

Saturn's gleaming white moon Enceladus has a thin, transient atmosphere of water vapor, say Cassini scientists. The discovery came after close passes February 17 and March 9.

Cassini's magnetometer saw the moon's magnetic field vibrating at a frequency that indicates Enceladus is wrapped in a cloud of water vapor electrically charged by sunlight.

The ionized atmosphere is continually escaping into space, so it needs steady replenishment. Says Michele Dougherty, principal investigator for the magnetometer, "These results may be the first evidence of gases originating at the surface or possibly in the moon's interior." — ROBERT BURNHAM

NASA/JPL/UNIVERSITY OF ARIZONA

FALSE COLOR. Cassini's infrared spectrometer depicts pure ice as blue and large ice grains or minerals as red.

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GALACTIC ZOO. New results show the early universe held an unexpected variety of galaxy types, including dead ones.

Early universe a "zoo" of galaxies

For years astronomers believed the early universe was filled with young protogalaxies busily forming stars. Now, however, it appears the universe contained "dead" galaxies as well as young, active ones when it was 2 to 3 billion years old.

Astronomers at the Carnegie Observatories and the Harvard-Smithsonian Center for Astrophysics (CfA) used the Spitzer Space Telescope to look at a southern region of the Hubble Deep Field.

There they found old, red galaxies no longer making stars because the galaxies had run out of gas to make them with. The discovery implies galaxies formed earlier than previously thought and ran through the entire cycle of star formation before the universe aged 3 billion years.

The astronomers also found the early universe was unexpectedly complex, with many different types of galaxies.

Ivo Labbè, co-author of a study to appear in *The Astrophysical Journal Letters*, says, "Overall, we're seeing young galaxies with lots of dust, young galaxies with no dust, old galaxies with lots of dust, and old galaxies with no dust."

Co-author Jiasheng Huang (CfA) adds, "We're detecting galaxies we never expected to find, with properties we never expected to see." — LIZ KRUESI

Watching space shuttles come home

Space shuttle blastoffs are gut-wrenching, with the threat of disaster always in mind. But on the next shuttle flight, the big tension will come at the mission's end, when the ship returns in a fireball through the atmosphere.

On February 1, 2003, the first to see the Columbia shuttle was in trouble were amateur astronomers in California. Looking through a video camera as sparks drifted from the main fireball, one young man can be heard to say, "Dad, there are pieces coming off."

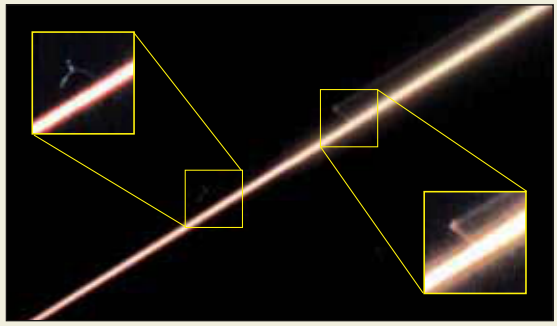
Indeed there were. A mortally wounded shuttle wing was already shedding fragments of its heat shield.

Eyewitness accounts and many photo and video records gave important forensic data to the investigators who ultimately found the disaster's cause.

Not all images were useful, however, including a bizarre image shot by Bill Goldie, a San Francisco area image-processing specialist.

The first time exposures he took that morning seemed to show a zig-zag purple bolt of lightning converging on the shuttle.

At first, some researchers wondered whether it was some unknown ionospheric phenomenon, or even an artifact of some man-made experiment.



NASA/JSC

LIGHTNING BOLT? A double-exposure in a camera frame (showing the shuttle Columbia returning) produced what looks like a bolt of lightning to one side of Columbia's fireball.

A more prosaic answer soon appeared, however. Goldie had depressed the shutter button with Columbia in the center of the field of view and its white trail stretched across the sky.

The camera jiggled briefly, then settled. The zig-zag trail was from the fireball itself, and once stable, the camera recorded the persistent trail that already existed, as well as a brighter segment where the fireball went out of view.

But views like these showing a dark-sky shuttle entry won't recur as before.

Of more than 100 space shuttle flights, only about a dozen crossed the United States from west to east in darkness. Most missions landed in daylight, or in California with the fiery trail visible only over the Pacific.

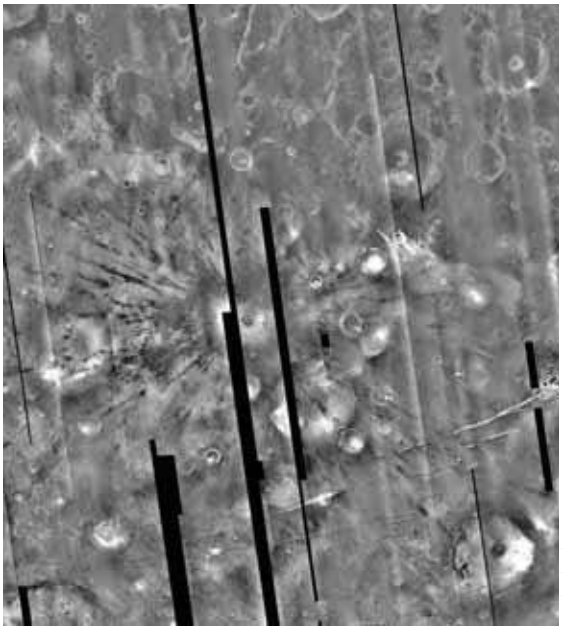
Many others flew on orbits more steeply inclined to the equator, approaching Florida from the southwest, over the Gulf of Mexico.

All future shuttle missions will fly to the space station, with its high-inclination orbit path, so future entries will come across the Yucatán Peninsula in Mexico, varying a few hundred miles east or west. Never again will a returning shuttle trace a fireball through the skies over the United States.

For the first few shuttle entries this year, NASA will observe the entry with high-flying aircraft. But if early flights are "nominal," this expensive effort will end, leaving the skies again to amateur eyes.

Then a new population of amateur astronomers will arise, this time in Latin America. They will experience the awesome sight of a golden-yellow spark with a slowly fading white trail, followed many minutes later by the dull thud of a hypersonic boom.

Here's wishing them "clear skies" — or maybe that should be "*cielos claros*." — JAMES OBERG



NASA/JPL/ASU/UNIVERSITY OF TENNESSEE

THROWING ROCKS. Rays make dark streaks around Gratteri Crater, 4.3 miles (6.9 km) across, in a nighttime infrared view. Gratteri may be the source of the oldest Mars meteorite, ALH84001.

Chipping pieces off Mars

Newly discovered martian craters with rays may be the long-sought sources for the Mars meteorites found on Earth, according to researchers.

Ray craters are common on the Moon, but only one ray crater was known on Mars until a team led by Livio Tornabene of the University of Tennessee, Knoxville, found four more ray craters plus three probables. "We didn't find ray craters before because we were looking in visible light," Tornabene says. "But on Mars, rays show in the thermal infrared."

The ray craters range in diameter from 1 to 6 miles (1.5 to 10 km). Most lie on plains dating from the most recent period in martian geological history, the Amazonian. That suggests a link to martian meteorites, pieces of Mars ejected 700,000 to 20 million years ago. Their sources on Mars remain unknown.

"Most martian meteorites are young," says Tornabene, "so most of them should come from Amazonian-age terrain."

Oblique impacts that make rays could launch rocks from Mars without destroying them, explains Tornabene. "Material on the surface near the impact is ejected at high speed without being greatly shocked."

Craters from oblique impacts typically have asymmetric shapes and ray patterns. Says Tornabene, "If we could send a rover to one of these sites, we could confirm the idea — or disprove it." — R. B.

NASA/JPL/CORNELL UNIVERSITY

ELUSIVE WHIRLWINDS. Spirit imaged the first Mars dust devil seen by either rover.

Dust devil gives rover the brushoff

In Gusev Crater on Mars, Spirit had its solar panels blown clean by a dust devil that passed over the rover, and a day later it took a photo of two dust devils on the crater's plains.

"Solar power went from 40 percent reduced to only 7 percent reduced," says Matt Golombek (Jet Propulsion Laboratory). "That's a 50-percent improvement in a single day!"

Dust devils have been rare during the rover missions so far, but that's about to change. Says Golombek, "We're coming into a season when dust devils are more likely to occur." — R. B.

Glaciers on Mars

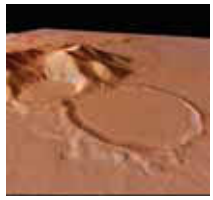
Glaciers left unmistakable traces in the martian tropics and mid-latitudes, say scientists studying images from Mars Express' High-Resolution Stereo Camera (HRSC).

A team led by James W. Head (Brown University) reports that detailed images of eastern Hellas show debris at the foot of ridges, mountains, and valleys. These have flow marks similar to those of terrestrial glaciers. Their report appeared in *Nature* (March 17, 2005).

According to the scientists, Mars is emerging from a glacial epoch when polar ice collected at low latitudes, building glaciers.

This latest Ice Age occurred when Mars' rotation axis had a greater tilt than today's 25°.

"Abundant residual ice probably remains in these deposits," say the scientists. — R. B.



ESA/FU-BERLIN, G. NEUKUM

ICY HOURGLASS. This martian mountain fed a valley glacier that filled two adjoining craters with debris.

Taking Meteor Crater by swarm

A new theory proposes an impacting swarm of fragments, not a single object, made Meteor Crater in Arizona.

The crater was born 49,000 years ago when a nickel-iron meteorite blew a hole 4,000 feet (1,200 m) across. Past estimates said the object struck at 9 to 12 miles (15 to 20 km) per second.

Two scientists now calculate the crater came from a slower impact, about 7 to 8 miles (12 km) per second. What's more, say Jay Melosh (University of Arizona) and Gareth Collins (Imperial College, London), the impacting body broke up in the air and hit in pieces, leaving scant impact-melted rock or nickel-iron fragments.

But if more impact melt is found, says Melosh, that would indicate a more solid impactor. — R. B.

USGS/D. RODDY

IRON SHOWER. An apparent scarcity of impact-melted rock at Meteor Crater has led to a theory suggesting the crater was dug by a cloud of iron meteorites.

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Lumicon International offers the best and most extensive line of astronomical filters in the world. Filters for every imagined visual and astrophotographic application, in many configurations and sizes. Filters for light polluted skies, planets, deep sky objects, galaxies, nebulae, planetary nebulae, comets, and solar prominences. All Deep Sky, UHC, OIII, H-Beta, and Comet Filters are individually tested and proudly inscribed with the percentage of light transmittance of their primary emission lines. Lumicon also offers a complete line of unique accessories, including the World Famous Easy Guider Series, Sky Vector Systems, Diagonals, Finderscopes, and Binocular Viewers. To ensure that Lumicon Products remain the World's Best, the strictest quality control standards are employed throughout the production process. All Lumicon Products are made to the highest standards available and come with a 100% Satisfaction Guarantee - Please Visit www.lumicon.com for Details.

DEEP SKY FILTERS The best light pollution filter on the market today. Blocks all high & low pressure mercury and sodium vapor lamp light, neon lights and airglow, while transmitting the rest of the visible spectrum. Excellent for both visual and photographic applications. Visually, the Deep Sky Filter is most useful under light-polluted skies, from where it reveals faint objects like star clusters, galaxies, nebulae and comets by darkening the background of space. Photographically, the Deep Sky Filter enables deep space photos to be taken through city lights and blocks natural airglow at dark-sky sites, thus improving results in film and CCD astrophotography.

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

ULTRA HIGH CONTRAST FILTERS The ULTIMATE nebula filter. The original LUMICON Ultra High Contrast Filter is unbeatable for revealing nebulosity. This achievement in filter performance is attributed to exclusively designed coatings that isolate the two doubly ionized oxygen lines (496 and 501nm) and the H-beta line (486nm) emitted by planetary and most emission nebulae. The result is superb views of the Orion, Lagoon, Swan and other extended nebulae. Useful to great advantage under dark skies.

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

OXYGEN III FILTERS The legendary LUMICON OIII narrow bandpass filter isolates just the two doubly ionized oxygen lines (496 and 501nm lines) emitted by diffuse, planetary and extremely faint nebulae. Thus, these faint objects become much more visible against the blackened background of space. The LUMICON Oxygen III Filter produces near-photographic views of the Veil, Ring, Dumbbell and Orion nebula, among many other objects. Performs best under both light-polluted and dark skies. You will be amazed at what the OIII filter allows you to see!

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

HYDROGEN-BETA FILTERS The Horsehead Nebula filter. The LUMICON H-Beta Filter isolates only the hydrogen-beta line of the spectrum (486nm) in a narrow pass-band just 9 nm wide. The result is extreme contrast between the black background of space and the delicate Hydrogen - Beta emission of extended nebulae. Now you can view extremely faint, special objects such as the Horsehead, Cocoon and California Nebulae. In many cases, the LUMICON H-Beta Filter is the ONLY way to view these objects. A transparent sky, a 8" or larger telescope, and the LUMICON H-Beta Filter, will tremendously aid in viewing those "notch in the belt" objects.

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

COMET FILTERS The LUMICON Comet Filter, a narrow bandpass system (25nm), isolates the 501nm OIII line and both Cyanogen lines at 511nm and 514nm. The high contrast gain of the filter reveals the delicate ionized tail of gaseous comets, allowing you to see their full extent. The Comet Filter also helps you to better distinguish gaseous comets from dusty comets which normally show little contrast gain.

Howard Brewington, famed comet discoverer, says: "I discovered Comet Aarseth-Brewington, 1989a1, using the LUMICON Comet Filter. The filter doubled the contrast, making the comet very easy to spot." Why make comet-hunting harder than it needs to be?

1.25" – $99.95 • 1.25" Questar – $99.95
2" – $199.95 • Cassegrain Rear Cell – $199.95

NIGHT-SKY HYDROGEN-ALPHA FILTERS Not intended for solar observing, the LUMICON Night-Sky H-Alpha Filter is a powerful photographic aid in overcoming light pollution during deep-sky photography. It will greatly reduce light pollution, making it ideal for photography of faint emission nebulae. Exposures may be increased up to 10 times without diminishing the black background in your photograph, thus, achieving strikingly improved results in black & white film and CCD astrophotography. Both filter surfaces have high light transmittance coatings for maximum performance.

2" – $69.95 • 58mm – $79.95 • 77mm – $89.95 • 82mm – $99.95

MINUS VIOLET FILTERS The LUMICON Minus Violet Filter greatly improves photographs taken through lens systems, producing pinpoint star images. It is especially recommended for all telephoto lenses. The Minus Violet filter passes the maximum amount of visible light, including the full blue, green, yellow and red portions of the spectrum. It absorbs violet and ultraviolet light below 420nm, thus eliminating blue halos around bright stars in color photography. In B&W photography it eliminates bloated and swollen star images caused by violet and ultraviolet light, which telephoto lenses cannot focus perfectly, due to chromatic aberration. This filter is unsurpassed in photographic performance.

2" – $69.95 • 58mm – $79.95 • 72mm – $89.95

LUNAR AND PLANETARY FILTERS LUMICON Lunar and Planetary filters are made from renowned Schott and Hoya optical glass. Each filter is individually precision ground and highly polished with ultra-high light transmittance coatings on both sides for ultimate contrast on lunar and planetary detail. Double stacking filters may also improve lunar imaging. Optimized for both visual and photographic applications. For a complete list of lunar and planetary filters and applications, please visit www.lumicon.com. 1.25" – $19.95 • 2" – $29.95

POLARIZING FILTERS LUMICON Polarizing Filters are manufactured from optically flat Hoya polarized glass. Performs best at cutting all glare and increases contrast on bright celestial objects such as the moon at full illumination, and can be double-stacked with other LUMICON filters for use on bright planets. They are also useful for daylight observation of land, sea and nature. In addition to polarizing the light, they reduce its intensity by a factor of about 3.

Also available in rotating polarized cell designs for variable levels of light transmittance to any value between 5% and 30%.

Single Polarizer 1.25" – $29.95 • 2" – $39.95
Variable Polarizer 1.25" – $39.95 • 2" – $49.95

• NEW • NEW • NEW •

80MM SUPER FINDER SYSTEM The highest quality finder system on the market today, the newly redesigned LUMICON 80mm Super Finder features exceptionally sharp optics, high contrast views and easy to use functionality. The LUMICON 80mm Super Finder is designed to switch conveniently from straight through to right angle in seconds with supplied extension adapter. Includes a front barrel focuser for fast and precise focusing. In addition, the LUMICON 80mm Super Finder includes a correct image right angle diagonal for hassle free pointing in any direction.

The LUMICON 80mm Super Finder also doubles as a high quality rich field refractor, yielding superb views of the moon, planets, star clusters, bright galaxies as well as daytime images. Use it with the optional Image Visor and reduce glare while increasing contrast and resolution on lunar and terrestrial views.

Objective Lens: Fully Multi-Coated 80mm Achromatic Lens; Focal length: 300mm; Includes a Quality 25mm Kellner Crosshair Eyepiece; Super Finder System Weight: 2.7 lbs. Body color available in Black or White.

80mm Super Finder System – **$299.95**
80mm Super Finder Body (Body Only) – **$219.95**
Image Visor – **$24.95**
2X Fully Coated Barlow Lens – **$39.95**

UNIVERSAL DOVETAIL FINDERSCOPE BRACKETS The LUMICON Universal Dovetail Finderscope Bracket will securely hold your finderscope to your telescope. The dovetail design permits fast removal and reinstallation of your finderscope while maintaining the alignment to your telescope. Mounts on most telescope tubes, with adjustments for other tube designs. Made from solid aircraft aluminum.

50mm Universal Dovetail Finderscope Bracket – **$49.95**
80mm Universal Dovetail Finderscope Bracket – **$59.95**
Universal Dovetail Bracket Spare Base – **$14.95**
Universal Dovetail Bracket Tripod Mounting Base – **$19.95**

MULTIPLE FILTER SELECTORS LUMICON Multiple Filter Selectors allow you to switch back and forth between filters without having to thread and unthread them from your eyepieces or diagonal. The nose-piece also has threads, so one filter, such as a neutral density or polarizing filter, can be "stacked" with the others. Leaving one of the slots open lets you compare views with and without your LUMICON filters. Made from solid aircraft aluminum.

1.25" Multiple Filter Selector Features: Fits Standard 1.25" Filters; 5 Filter Positions; 6oz Light Weight Construction; 5/8" Low Profile Design; Includes 1.25" Eyepiece Adapter and T-Thread Adapter. Price – **$129.95**

NEW 2" Multiple Filter Selector Features: Fits Standard 2" Filters; 4 Filter Positions; Light Baffles for Astrophotography; 8oz Light Weight Construction; 5/8" Low Profile Design; Includes 2" Eyepiece Adapter and Male Cassegrain Rear Cell Adapter. *Filters sold separately.*

Introductory Price: **$169.95**

ADVANCED CLEANING KIT The very best cleaning kit ever offered. The LUMICON Advanced Cleaning Kit has everything you need to clean even the most delicate lenses and mirrors. Safe to use on all optical surfaces. Includes LUMICON Lens Cleaning Spray, LUMICON Multi Coated Optics Cleaning Fluid, LUMICON Lens Cleaning Tissue, Ultra Brush Dust Remover, Air Blower Blush, 100% Cotton Swabs, LUMICON Micro-Fiber Cleaning Cloth, "Blow Off" Com- pressed Air and a Hard Carrying Case.

Introductory Price: **$39.95**

SOLAR PROMINENCE FILTER SYSTEM

The LUMICON Solar Prominence Filter System converts your existing telescope into a Hydrogen – Alpha solar telescope. Viewing the sun in Hydrogen – Alpha light allows for amazing images of solar prominences, solar flares, sun spots, bright filaments and other surface features. Simply use a standard camera T-Ring and SLR camera for full photographic capability. Safely observe and photograph the sun at high and low powers directly through your own telescope.

The LUMICON Solar Prominence Filter System includes three components: 1. The Energy Rejection Prefilter; blocks all harmful radiation before it enters your telescope. 2. The Off-Axis Mask; stops down your objective and holds the Energy Rejection Prefilter. 3. The SPF Body; extremely narrow-band (1.5 Angstrom) Hydrogen-Alpha filter, providing high contrast imaging of solar features. This portion of the filter slides into a 2" focuser or diagonal. Includes a T-Thread camera adapter and a 1.25" eyepiece adapter.

Solar Prominence Filter System for 7" / 8" Cassegrain – $779.95 • Meade 10" SCT – $789.95 • Celestron 11" SCT – $799.95 • Meade 12" SCT – $809.95 • Celestron 14" SCT – $819.95 • Meade 14" SCT – $819.95 • Meade 16" SCT – $899.95

Solar Prominence Filter Kit available for telescopes not listed here. The Off-Axis Mask is not included and can be fabricated by customer. Price - $699.95

For more information, visit www.lumicon.com

DIAGONALS

Enhanced Mirror Diagonals

With 96 - 97 percent light reflectivity, 1/10 wave precision polished optics and individually performed double pass collimation tests, the LUMICON Enhanced Diagonal is a must for a fast and significant upgrade from any standard prism diagonal. Includes standard filter threads for trouble-free changing of eyepieces and accessories while using filters. Made from solid aircraft aluminum.

1.25" Enhanced Diagonal - $99.95
2" Enhanced Diagonal - $189.95

LumiBrite Mirror Diagonals

With greater than 98 percent light reflectivity, 1/10 wave precision polished optics and individually performed double pass collimation tests, the LUMICON Lumi-Brite Diagonal maximizes the performance of your telescope for ultimate contrast and resolution one can get from a star diagonal. The exceptional Dielectric Coating provides for a more durable and longer lasting surface. Additionally, objects appear much brighter, with truer color. Includes standard filter threads for trouble-free changing of eyepieces and accessories while using filters. Made from solid aircraft aluminum.

1.25" LumiBrite Diagonal – $149.95
2" LumiBrite Diagonal – $239.95

Prism Diagonals

1.25" Multi-Coated Prism Diagonal – $49.95
1.25" 90° Correct Image Diagonal – $69.95

BINOVIEWER

The LUMICON BinoViewer allows you to comfortably use both eyes while looking through your telescope. The efficiently designed light beam splitter allows for minimum light loss and improved image contrast up to 40 percent. The LUMICON BinoViewer uses precision polished, Grade-A BK 7 crown glass with the highest contrast and color correction available. Its fully multi-coated optics and roof prism design provides for maximum light transmittance, freedom from ghosting images, and built in image correction. Installs in seconds into standard 1.25" focusers or diagonals. Eyepieces not included.

Specifications: Clear Aperture: 22mm; Focus Travel: 20mm; 1.25" Barrel, Threaded for Filters; Magnification: 1X; Overall Length: 120mm; Weight: 23 oz.

Price – $799.95

EASY GUIDERS SYSTEMS

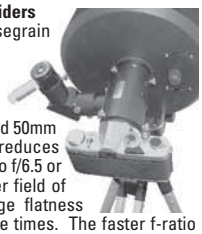
The most powerful astrophotographic accessory available today. LUMICON Easy Guiders feature patented radial and rotational off-axis adjustments, combined with a large off-axis pick off prism, selecting bright guide stars becomes a breeze for manual astrophotography or computer controlled auto-guiding.

Newtonian / Refractor Easy Guiders

The LUMICON Newtonian/Refractor Easy Guider allows off-axis guiding directly through the main telescope, preventing differential flexure between your telescope and guide scope, which can ruin your astrophotos. The low profile design installs in seconds into standard 1.25" and 2" focusers. Accommodates standard filters and camera T-Rings.

Newtonian/Refractor Easy Guider 1.25" – $189.95
2" – $189.95

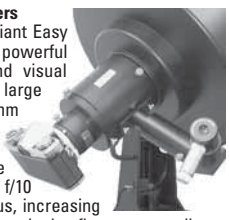
Cassegrain Easy Guiders



The LUMICON Cassegrain Easy Guider allows off-axis guiding with your 5" – 9.25" cassegrain telescope. The included multi-coated 50mm focal reducing lens reduces the f-ratio from f/10 to f/6.5 or f/5, providing a wider field of view, increased edge flatness and shorter exposure times. The faster f-ratio combined with the ease of finding and guiding on bright stars, minimizes guiding error, making for successful astrophotos. Accommodates standard 2" filters and camera T-Rings.

Cassegrain Easy Guider for Celestron 5" – $249.95 • 7" - 9.25" – $249.95

Giant Easy Guiders



The LUMICON Giant Easy Guider is a very powerful photographic and visual tool. Utilizing a large multi-coated 80mm focal reducing lens, the f-ratio of your telescope is reduced from f/10 to f/6.5 or f/5, thus, increasing your field of view and edge flatness as wells as decreasing exposure times. Unlike other focal reducing lenses, the LUMICON Giant Easy Guider has full frame illumination and pin-point star images on 35mm film, 120 format film and large format CCD cameras. Accommodates standard 2" filters and camera T-Rings. Meade 16" LX200 requires separate adapter.

Giant Easy Guider Meade 10" - 16" SCT – $399.95 • Celestron 11" - 14" SCT – $399.95

Easy Guider Accessories

Cassegrain Easy Guider SCT Accessory Adapter – $39.95 • Giant Easy Guider Adapter to Meade 16" LX200 – $169.95 • F/10 Viewing Adapter – $89.95 • SCT Accessory Adapter – $49.95 • Helicoid Focusable Off-Axis Tube – $79.95 • Giant Easy Guider Adapter Ring for Meade or Celestron – $49.95 • Newtonian/Refractor Easy Guider 2" Threaded Focal Reducer – $79.95

CAMERA T-RINGS

Canon, Canon EOS, Konica, Minolta, Minolta Maxxum, Nikon, Olympus, Pentax-K, Pentax-S – $19.95

EYEPIECES AND ILLUMINATORS

25mm Fully Multi-Coated Kellner Crosshair Eyepiece – $69.95
• 12.5mm Orthoscopic Eyepiece with Illuminated Reticle – $149.95 • Pulseguide Illuminator – $49.95

CAMERA ADAPTERS

Prime Focus Camera Adapters: .965" – $19.95 • 1.25" – $24.95 • 2" – $49.95 • Eyepiece Projection Camera Adapters: .965" – $39.95 • 1.25" – $39.95 • 1.25" Eyepiece - T-thread Adapter – $29.95 • 2" – $49.95 • 2" Male Adapter w/ Filter Threads to Male T-Thread – $29.95 • Cassegrain Tele-Extender – $29.95

UNIVERSAL DIGI-CAM ADAPTER

The most versatile digital camera adapter available today. Attach any digital camera, with a standard 1/4"x20 tripod thread, directly to your telescope or spotting scope. Includes fine motion controls for precise alignment. No tripods or brand specific T-Ring necessary. Made from solid aircraft aluminum.

Price: $39.95

DELUXE PIGGYBACK MOUNTS

The LUMICON Deluxe Piggyback Mount allows you to mount cameras or small telescope having 1/4" x 20 threads, onto medium and large telescopes. The LUMICON Deluxe Piggyback Mount is adjustable in altitude and azimuth, thus allowing you to align your camera with the optics of your main telescope. Four radii available for closest fit to your telescope tube.

Deluxe Piggyback Mount 6" – $59.95
Deluxe Piggyback Mount 8" – $59.95
Deluxe Piggyback Mount 10" - 12" – $59.95
Deluxe Piggyback Mount 14" – $59.95

RICH-FIELD VIEWERS

Cassegrain Rich-Field Viewers

The LUMICON Rich-Field Viewer takes your cassegrain's f/10 optics and reduces it to f/6.3 for beautiful low power, wide-angle views. Its multi-coated reducing lens has a large clear aperture, less coma than higher priced focal reducers on the market, while providing superb unvignetted views. Accommo- dates 2" diagonals and accessories.

Cassegrain Rich-Field Viewer for 5" - 9.25" – $99.95

Giant Rich-Field Viewers

The same high quality 80mm multi-coated optical system and fine machining of LUMICON's famous Giant Easy Guiders are incorporated into LUMICON's Giant Rich-Field Viewer. Converting your cassegrain's f-ratio from f/10 to f/6.5 or f/5 provides for the maximum brightness and field of view your telescope allows. Ultimately, this feature will allow for the widest possible views of large galaxies like the Andromeda Galaxy, the Triangulum Galaxy, NGC 253, and pairs of galaxies like M81and M82. Accommodates 2" diagonals and accessories. Meade 16" LX200 requires separate adapter.

Giant Rich-Field Viewer Meade 10"-16" SCT – $279.95 • Celestron 11"-14" SCT – $279.95

SKY VECTOR SYSTEMS

The LUMICON Sky Vector System is a state-of-the-art digital setting circle system, providing virtually any astronomical telescope, whether equatorial or altazimuth, with a continuous, real-time digital readout of right ascension and declination coordinates. With the LUMICON Sky Vector, you will be able to find objects even faster than with most fully computer-driven telescopes. Its alphanumeric display uses a simple, easy-to-read scrolling text format. There is no need to polar align or to enter Latitude, Longitude, Date, Altitude, and Sidereal time – just initialize on one or two stars and you're ready to go! Includes Mounting Hardware.

Sky Vector 1 - The LUMICON Sky Vector 1 features: One or two star initialization; 4000-step encoders for high-resolution accuracy (0.09 deg.); Digital Right Ascension coordinate readout to 1 minute; Digital Declination readout to 10 arc-minutes; Guide mode for guiding you to the selected object in current memory; Database containing over 220 of the showpiece objects in the sky, including the famed "Messier Catalog." Price – $349.95

NGC Sky Vector - The LUMICON NGC Sky Vector has all the features of the Sky Vector 1, plus a large 12,000 object database; higher resolution display modes; IDENTIFY mode; and current constellation and chart number displays - all on a 16-digit red LED display. It can also be integrated with a personal computer for display of celestial object coordinates. Price – $489.95

Sky Vector Mounting Hardware available for the following telescopes: Celestron C5+, Early Model C8, Celestar 8, Celestar 8 DLX, Ultima 9.25 / 8 / 11, C11, C14; Meade LX10, 2080, 2120; 8" – 17" Dobsonian. From $69.95

Mounting Hardware can be fabricated by owner if telescope is not listed here. For more information, visit www.lumicon.com

SKY VECTOR ACCESSORIES

Sky Vector 1 Computer Kit – $269.95 • NGC Sky Vector Computer Kit – $419.95 • High Resolution 8192 Step Encoder Upgrade with Purchase – $29.95 • Version 3.68 Upgrade Chip for NGC Sky Vector – $59.95 • Serial Cable for NGC Sky Vector – $29.95

UNIVERSAL LASER POINTER BRACKET

The best selling LUMICON Universal Laser Pointer Bracket is designed to work with most popular red and green laser pointers. Easily attaches to your telescope with supplied mounting hardware. Now you can accurately point your telescope to the stars without sacrificing comfort. Includes advanced safety features and engineered for a lifetime of use. Made from solid aircraft aluminum.

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1.3" LumiBrite Secondary Mirror – $99.95
1.8" LumiBrite Secondary Mirror – $149.95

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1.25" Extension Tube 2" Long – $19.95
1.25" Extension Tube 4.5" Long – $29.95
2" Extension Tube 2" Long Thread-In – $24.95
2" Extension Tube 2" Long – $24.95
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REDUCERS AND ADAPTERS

1.25" - .965" Reducer – $24.95
2" - 1.25" Reducer – $24.95
.965" - 1.25" Adapter – $24.95
1.25" – 2" Adapter – $39.95
2" Accessory Adapter for Cassegrain – $39.95

STEP RINGS

48mm to 46mm, 48mm to 49mm, 49mm to 48mm, 52mm to 48mm, 52mm to 58mm – $11.95
55mm to 48mm, 55mm to 58mm, 58mm to 48mm, 62mm to 58mm – $12.95
62mm to 72mm – $14.95
67mm to 62mm, 67mm to 72mm, 67mm to 77mm, 72mm to 67mm, 72mm to 77mm, 77mm to 67mm, 77mm to 72mm, 77mm to 82mm, 82mm to 77mm – $15.95

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RADIO REPEATER. Astronomers analyzing old data have discovered a new kind of object near the Milky Way's center. In a 7-hour period in 2002, it emitted five 10-minute bursts of radio noise every 77 minutes.

NASA/JPL/MSSS/IMAGE M03-04703

Inverted lava channel

RAISED STREAMBED. The raised ridge is a stream of lava that flowed down a valley in Mars' Memnonia Sulcis. After the surrounding rocks eroded away, the more-resistant lava stream was left as a low ridge. This Mars Global Surveyor image, sunlit from the upper left, is about 1.9 miles (3 km) across.

NASA

DIFFICULT BIRTH? A star factory in Corona Australis contains a young protostar emitting X rays in flare-like outbursts.

X-raying a starbirth

A stellar newborn less than 100,000 years old is emitting X rays from the depths of a cold cloud of dusty gas, surprising a team of astronomers.

"This is no gentle infall of gas," says team member Michael Corcoran (Goddard Space Flight Center). "Forces seem to be accelerating matter to high speeds, heating parts of the gas cloud to 100 million degrees Fahrenheit."

Solar flares, say the astronomers, may be a local example of the process generating the X rays.

"Young stars have the same kind of activity as the Sun," says Corcoran, "but on a larger scale." — R. B.

NASA/JPL/MSSS/IMAGE R15-00460

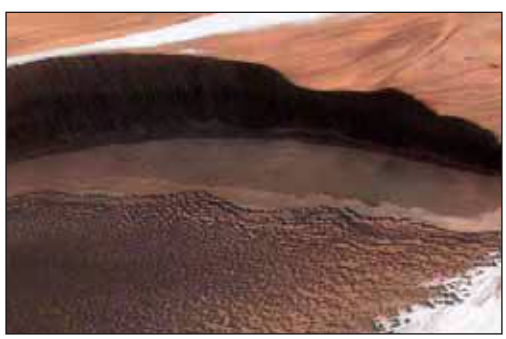
DOUBLE BURIAL. Dark dunes are creeping across the floor of a large crater in Mars' southern Noachis Terra. The small crater at lower right contains older deposits of light-tinted, wind-blown debris. Sunlit from the upper left, this image from Mars Global Surveyor spans 1.9 miles (3 km).

North polar volcanism on Mars

New Mars Express images show features near Mars' north polar cap suggesting volcanic activity.

Layers of water ice alternate with darker layers of dust in cliffs reaching almost 7,500 feet (2,000 meters) high. The layers hint Mars has seen cycles of climatic change.

Several volcanic cones up to 2,000 feet (600 m) high stand near the polar cap. Ash erupted from them may be the source of the dark material forming dunes in regions around the polar cap. — R. B.



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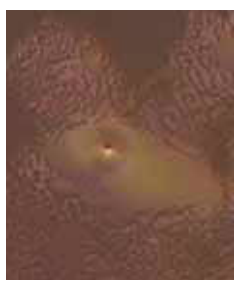

ESA/DLR/FU-BERLIN, G. NEUKUM

ASH AND ICE. Dark material in the wavy dunes (above) may be volcanic ash that weathered from the ice. At right, a dune field surrounds a volcanic cone.

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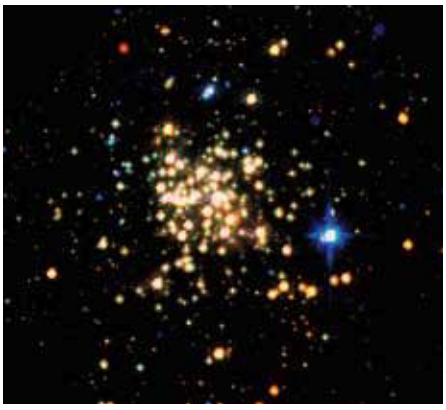
DINKY STAR. Astronomers hunting extrasolar planets transiting a star's disk have found the smallest main-sequence star known, an M-type dwarf, OGLE-TR-122b. It has only 1/8 the Sun's diameter and 1/10 its mass.



NASA/ESA/STScI, D. FIGER

BIG BABIES. In principle, stars could be born huge, weighing hundreds of Suns. But two studies, one of which focused on the Arches cluster (above), found nature imposes a top limit.

Diet of the stars

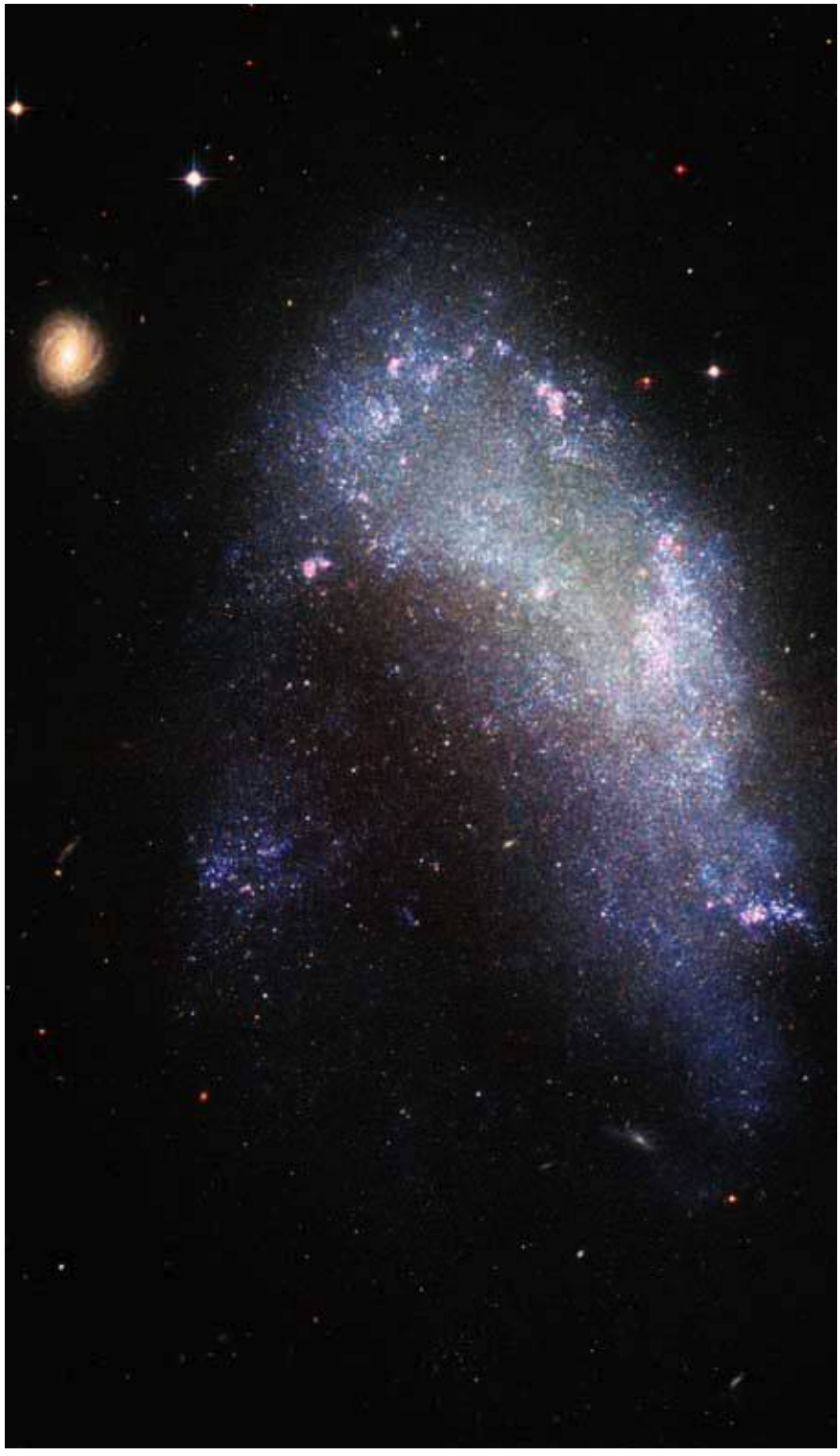
At birth, stars weigh no more than 150 Suns, says astronomer Donald Figer (Space Telescope Science Institute). He used the Hubble Space Telescope's NICMOS camera to inventory the rich Arches star cluster near the Milky Way's center.

When he measured the masses of the cluster's stars, he found none weighing more than 150 solar masses.

"This is one of the densest young star clusters in the Milky Way," says Figer. He adds that it is 2 to 2.5 million years old — young enough not to have already lost its most massive stars through supernovae.

The new finding, published in *Nature* (March 10, 2005), supports a recent study in *Astrophysical Journal Letters* (February 10, 2005). In that paper, Sally Oey (University of Michigan) and Cathie Clarke (Institute of Astronomy, Cambridge, England) examine nine star clusters and associations, not including the Arches cluster. They find the heaviest stars weigh 120 to 200 solar masses.

Theorists aren't sure how nature puts a limit on stellar masses. But Stan Woosley (University of California, Santa Cruz) favors radiation pressure. "Above about 100 solar masses," he says, "the pressure holding up a star comes from light itself. So 150 solar masses might be the last point at which a star is not overwhelmed by its own radiation." — R. B.



NASA/ESA/HUBBLE HERITAGE TEAM

NGC 1427A: falling in with a bad crowd

EVE OF DESTRUCTION. The irregular galaxy NGC 1427A, lying 62 million light-years away, belongs to the Fornax galaxy cluster. It shines bluish white, thanks to many hot, new stars. But over the next billion years, NGC 1427A will be torn apart by the gravitational forces of other member-galaxies.

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Professor Michael Starbird is a distinguished and highly popular teacher with an uncommon talent for making the wonders of mathematics clear to non-mathematicians. He is Professor of Mathematics and a Distinguished Teaching Professor at The University of Texas at Austin, where he has received the President's Associates Teaching Award, the Jean Holloway Award for Teaching Excellence, and the Friar Society Centennial Teaching Fellowship.

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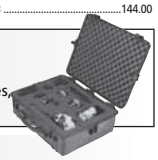

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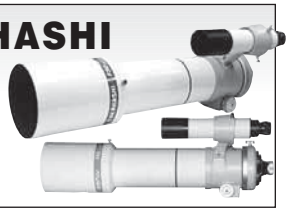

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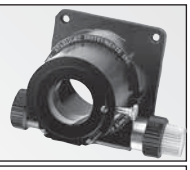

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The hot, violent world of ga

THE HERCULES GALAXY CLUSTER, 650 million light-years away, contains a lot of spiral and irregular galaxies, many in pairs and triplets. Astronomers have long theorized that gas in a galaxy cluster's center radiates away most of its heat — but they're finding gas in clusters at higher temperatures than expected.

KPNO/V. ANDERSEN, W. KEEL

It's a muddle in the middle. The gas in the center of galaxy clusters isn't as cool as expected, reports Steve Nadis. Something is heating it, but what?

For more than 2 decades, astronomers thought they had a good grasp of what was happening in the center of galaxy clusters. Understanding clusters of galaxies is no small matter — they're the largest gravitationally bound structures in the universe.

The biggest ones, stretching more than 5 million light-years across, contain thousands of galaxies with the combined mass of a quadrillion Suns. Stars and galaxies, however, make up just a small percent of a cluster's mass.

These visible cluster members, in turn, lie embedded in a fog of hot gas (typically 10 to 100 million kelvins) that accounts for about 20 percent of the total mass, with unseen dark matter comprising the remaining 70 to 80 percent.

Until recently, the standard story for the origin of galaxy clusters went much as follows: Clusters form by gravitational collapse, as groups of galaxies and smaller clumps draw together. In a cluster's center, where the universe's biggest and brightest galaxies reside, gravitational forces crush what had been diffuse gas to high densities until it glows in X rays.

With radiation steadily carrying away its heat, the gas cools and shrinks, reducing pressure in the core. To fill the void, hotter gas from the cluster exterior flows toward the center, where it becomes compressed, radiates, and cools.

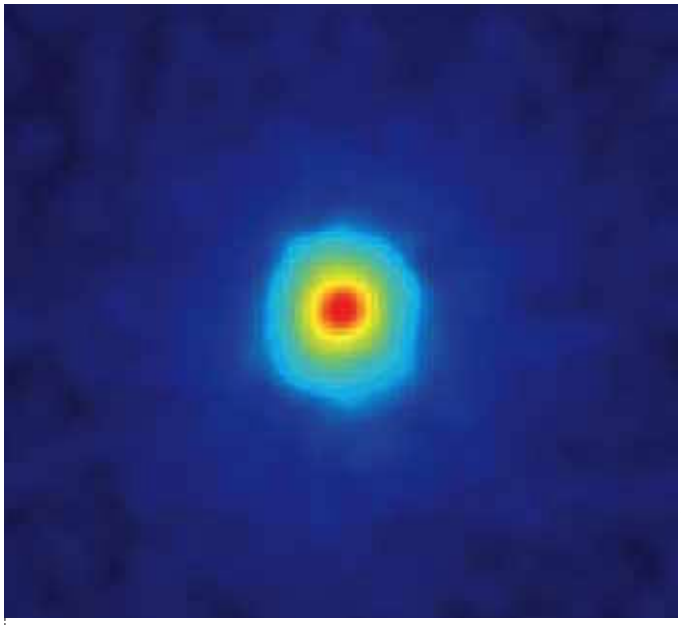
Theorists envisioned a slow, steady stream of gas slumping inward from a cluster's outskirts — a bulk motion they called a "cooling flow." This model became the prevailing view soon after it was proposed in 1977.

Although the idea had a long run, says Paul Nulsen of the Harvard-Smithsonian Center for Astrophysics (CfA), who coauthored one of the original 1977 papers, "We now think it's almost completely wrong." The simple inflow scenario has been replaced by a more complex picture that involves both heating and cooling, although the details have not been worked out fully.

Despite the fact that the cooling-flow model has run afoul of the latest data, gas cooling is still pronounced in more than half the clusters observed, as evidenced by sharp density peaks and heightened X-ray emission in their centers. But the amount of cool gas detected is lower — by at least tenfold — than astronomers expected, given the rate at which the gas spews out X rays. Theorists are scrambling to explain this shortfall.

"We thought we knew how clusters worked, but nature, apparently, doesn't do it that way," says Harvard astronomer Ramesh Narayan. "There's something going on here we don't understand, which makes for a nice puzzle."

laxy clusters



JOHN R. PETERSON/STANFORD UNIVERSITY

GALAXY CLUSTER ABELL 1835 lies in Virgo, 4 to 5 billion light-years away. Just as with other galaxy clusters, when astronomers observed Abell 1835 in X rays, they found gas in the heart of the cluster had not cooled as much as expected.

Focusing on flow

A big blow to the cooling-flow model came when John Peterson of Stanford University (then at Columbia University) and colleagues measured cluster Abell 1835 with a spectrograph on XMM-Newton, an orbital X-ray telescope. The researchers sought spectral lines from electrically charged atoms that reflect distinct temperature bands.

"Each spectral line is like a little thermometer," says Peterson. Curiously, they found gas that had cooled to one-third its starting temperature, which is still X-ray hot, but nothing below that. In 2001, the team published its findings in *Astronomy & Astrophysics*. A follow-up study published in 2003 documented the phenomenon in 14 different galaxy clusters, casting doubt on the existence of cooling flows.

The findings surprised Peterson, who expected their work would fill data gaps by detecting gas across a broad temperature range. "No one figured we'd be testing the whole cooling-flow model," he says.

Not only did they test the model, they virtually killed it. Astronomers now believe that cooling flows, if they exist, are reduced greatly. "The amount of gas flowing in is about 5- to 10-percent of what we originally thought," estimates Craig Sarazin of the University of Virginia.

But the mystery remains: Why does the gas cool down by two-thirds but no further? The best guess is that something is heating the gas back up again.

The idea is attractive because it can explain a discrepancy that has long bothered astronomers. X-ray observations suggest hundreds of solar masses worth of cool gas should be produced each year in clusters. That's a prescription for large-scale star formation, says Brian McNamara of Ohio University. "But when we measured rates of star-formation, we were getting 10 to 20 solar masses a year or less."

Steve Nadis, *an* Astronomy *contributing editor, writes often on cosmology, a field he finds easy to keep tabs on from his home in Cambridge, Massachusetts.*

McNamara spent much of the 1990s trying to figure out where nature was hiding this cool gas. In cold clouds? Low-mass stars? Neither he nor his colleagues could solve the riddle.

In 1999, McNamara found a tantalizing clue in Hydra A, a galaxy cluster 840 million light-years away. Observations with the Chandra X-ray Observatory revealed powerful radio jets — ultrahot streams of electrons emanating at nearly the speed of light from a supermassive black hole in the cluster's central galaxy — that were plowing into the surrounding gas and, presumably, heating it.

In 2005, McNamara, Nulsen, and five collaborators reported using Chandra to watch the same thing occurring on a grander scale in the distant cluster MS 0735.6+7421. The team discovered two enormous bubbles, or cavities, each roomy enough to house 600 Milky Ways, expanding from opposite sides of a supermassive black hole. They estimated the explosive energy required to displace hot gas from these cavities at more than 10^{61} ergs — equivalent to a billion gamma-ray bursts — making it the most powerful eruption seen anywhere, anytime.

Eventually, such cavities break into bits, releasing heat to the gas, McNamara says. But he admits the details of the heating process remain somewhat mysterious.

The bubbles are buoyant because their density is low, explains University of Colorado astrophysicist Mitchell Begelman. "They're not held in place by gravity, just as water bubbles are not kept down by gravity, either." Instead, the bubbles spread sideways as they rise through the cluster gas and distribute heat along the way.

An analysis by Nulsen and colleagues showed the energy needed to make the bubbles (by clearing away cluster gas) ultimately transfers to the gas. But it falls short by a factor of 3 in offsetting the heat lost in X-rays. Nulsen believes shock waves, as well as weaker sound waves, make up the difference.

Blowing bubbles

Shock waves blossom when jets from the core of a galaxy blow out a cavity, rapidly pushing gas and causing a sudden jump in pressure. (Astronomers call such a powerful core an active galactic nucleus, or AGN.) The distant cluster MS 0735 is an outstanding example, says McNamara, "because we actually see the shocks heating the gas and the resultant hot spots." Shock waves appear as sharp edges in X-ray images. The gas temperature and pressure shoot up along those edges — firm evidence of shock heating.

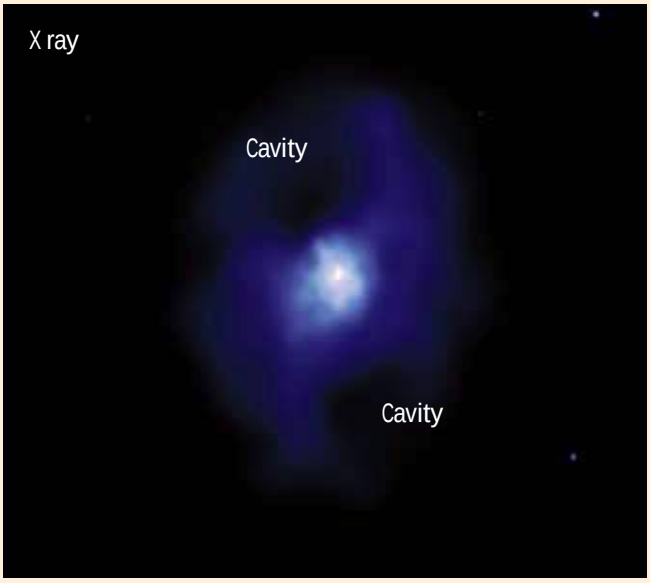
As bubbles rise in pulses, they generate sound waves, creating circular ripples that spread throughout the cluster and heat it. Circular patterns like this — similar to the ripples created by dropping a rock into water — were detected in the Perseus cluster in 2003 and in the Virgo cluster a year later.

In Virgo, the waves spread out from a giant (3-billion-solar-mass) black hole in the heart of M87, the cluster's dominant galaxy. Outbursts from this AGN occur about once every 10 million years, says William Forman of the CfA. "That may seem sporadic, but it's regular enough to keep the gas heated."

Until recently, astronomers had difficulty explaining how AGNs, whose activities are notoriously variable, give off just the right amount of heat to match the cooling seen in X-ray observations. The answer to this "fine-tuning" problem appears to be a feedback mechanism. An AGN shoots jets that heat gas in the vicinity. This cuts off the supply of cool gas feeding into the black hole. The AGN shuts down, allowing cluster gas to cool, until

/// TWO VAST CAVITIES

Two vast cavities yawn in the gas that pervades the galaxy cluster MS 0735.6+7421. The cavities — each 600,000 light-years across — result from jets powered by matter falling into the supermassive black hole at the heart of a galaxy in the cluster's center. As the jets erupt and clear the cavities of hot gas, they shut off the inflow of matter to the black hole, turning off the jets temporarily. Astronomers are studying this start-stop phenomenon as they try to understand why flows of gas in galaxy clusters run warmer than expected.



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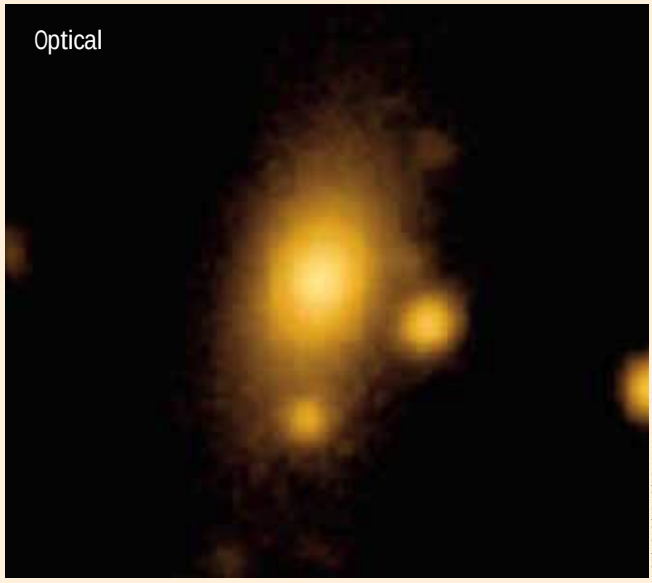

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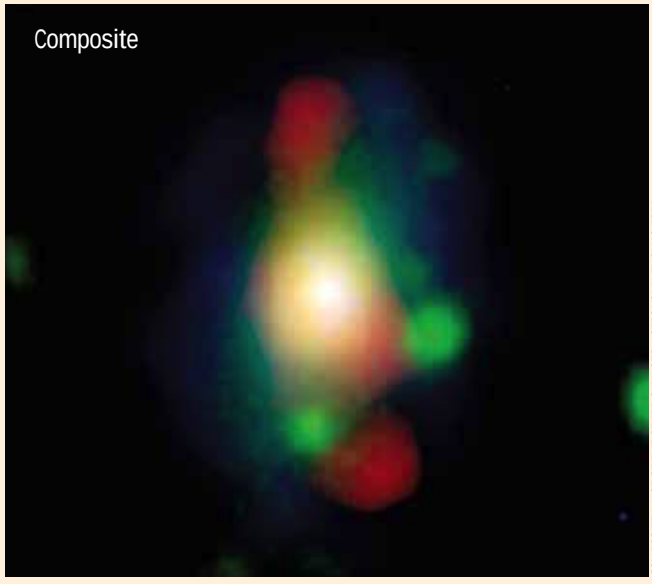


COMPOSITE IMAGE OF THE OTHER 3 IMAGES; *ASTRONOMY*: THOMAS FORD

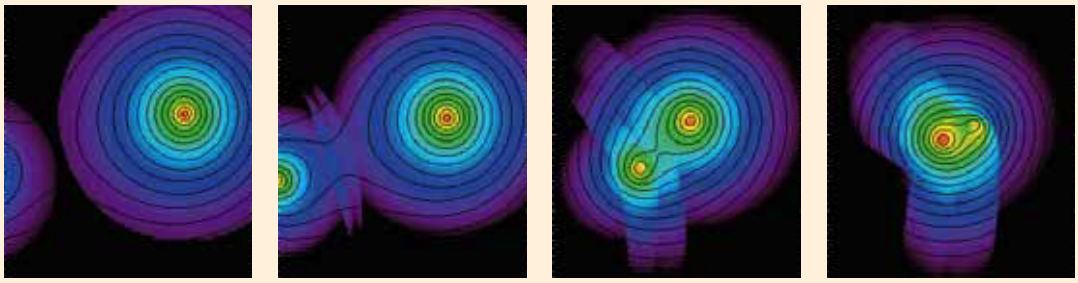
eventually it falls into the black hole. This sparks another outburst, and the cycle begins afresh.

Diminished cooling flows may survive, but instead of a straightforward, one-way flow, they're part of a "complicated, self-regulating loop," McNamara explains. "The thing creating the heat and regulating the inflow is the supermassive black hole in the center." Sometimes the feedback loop gets out of whack, he says. After an enormous outburst at MS 0735, for example, it can take a couple of billion years for the gas to cool again.

Self-regulating behavior may help explain the observed correlation between the mass of galaxies and the mass of the black holes in the galaxies' centers. The cooling-flow model turned out to be wrong for the same reason the masses of galaxies and their central black holes intertwine, notes Harvard theorist Abraham Loeb. "The black hole deposits enough energy into the surrounding medium to suppress its own growth and the growth of its host galaxy," he says.

The AGN picture, according to Forman, resolves several issues that had been nagging astronomers for years. Fortunately, he says, "all the bits and pieces seem to hang together." What's more, Forman is encouraged by the fact that 20 clusters have already been seen with bubbles and cavities carved out by AGNs. "The more people look, the more examples we find," he says. "These features seem to be very common."

A simulated collision between two galaxy clusters shows gas density in color and the gravitational field as contours. Mergers can take several billion years, with multiple shock waves passing through the gas, heating it as they go.



Not so fast

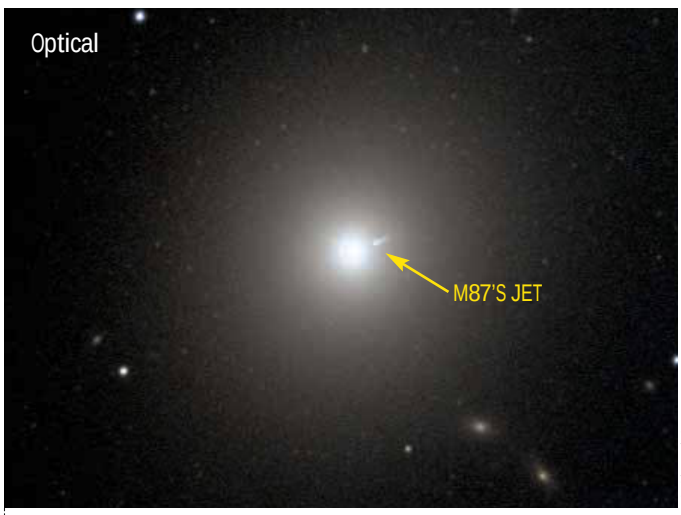
But before popping the champagne corks and designating AGNs the primary heating source, some questions need to be addressed. If AGN radio jets are responsible for heating cluster gas, why don't radio luminosities match X-ray cooling rates?

"There's not an obvious, one-to-one correlation between the two," Forman concedes. "They might still be correlated, but because of the long time-delay, you won't see it easily." That's a general problem in astronomy, he adds. "We rarely see anything in long time-sequences. Instead, we get little glimpses here and there, and it's all very messy."

The picture is confounded by the fact that black holes vary enormously in their output. During quiet periods, they're about as bright as the Sun. But when lots of material is falling into them, they shine a billion-billion times brighter. "The idea of feedback is that there's a cycle going on," Sarazin explains. "The average occurs over a period of time, so outputs don't have to match instantaneously."

Yutaka Fujita of the National Astronomical Observatory in Tokyo is unconvinced. He attributes the black-hole solution's popularity to a bandwagon effect. The biggest problem, he says, is cooling occurs in some clusters that bear no trace of AGN activity. That means there's no strict link between AGNs and cluster cooling.

CfA astronomer Maxim Markevitch agrees. The AGN mechanism is a safe bet in cooling clusters (roughly half the total), where AGNs have a "visible effect" on the gas, he says. "But in cases where AGNs do not have a significant impact, we need to consider alternatives."



NOAO/AURA/NSF

M87'S JET shows up clearly in this view of the inner regions of the giant elliptical galaxy at the heart of the Virgo cluster of galaxies.

For now, Fujita is promoting his own alternative called the "tsunami model." In it, pressure waves triggered by cluster mergers, the universe's most energetic events, deliver heat from the outer cluster to the core. The waves get amplified near the center as the medium becomes denser, just as tsunamis swell when they reach shallow water. In Fujita's computer simulations, the model reproduces the complicated X-ray structures seen in cluster cores.

The tsunami scenario is a specialized version of a broader class of models that heat cluster gas by transporting energy from one place to another. One way of doing this is through thermal conduction, which is the natural tendency for heat to move from hotter to cooler regions. Most astronomers assume conduction invariably will occur in galaxy clusters, although it may not have an appreciable impact on the central gas.

The other approach, called turbulent mixing, shuffles heat by stirring. "Clusters are constantly evolving systems, and a steady infall of material keeps the system stirred, as do more dramatic mergers," explains Narayan. Galaxies moving in orbit inside a cluster might also agitate the gas, although he hasn't seen reliable estimates of the energies involved in this process.

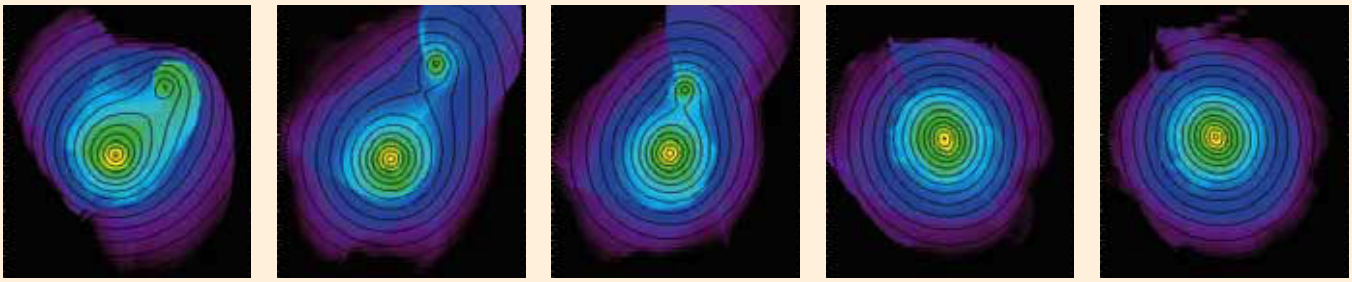
As far as understanding cluster heating and cooling goes, Narayan says, "it's still the early days. Therefore, we should explore all the possibilities."

University of Illinois astronomer Paul Ricker, who does large-scale computer simulations of galaxy clusters, shares Narayan's view that various processes contribute to heating on various scales. "We should be careful about drawing too many conclusions from a relatively low-resolution picture of the intracluster medium," Ricker says, given the uncertainties about gas velocities, magnetic fields, the influence of cosmic rays, and so forth.

Getting a better look

Most astronomers agree that more than one heating mechanism is in play, without necessarily agreeing on which one dominates. "Central regions of galaxy clusters are very rich environments, and there are undoubtedly several processes going on," says Sarazin. "AGNs, in my opinion, have the best chance of making the biggest contribution but are by no means the only mechanism."

Ultimately, Narayan says, "observations will help us figure out which, if any, of these ideas holds up." In the near future, he notes, Astro-E2, a Japanese-American mission due for launch this summer, offers the best chance of clarifying the picture because it can measure gas velocities inside clusters.



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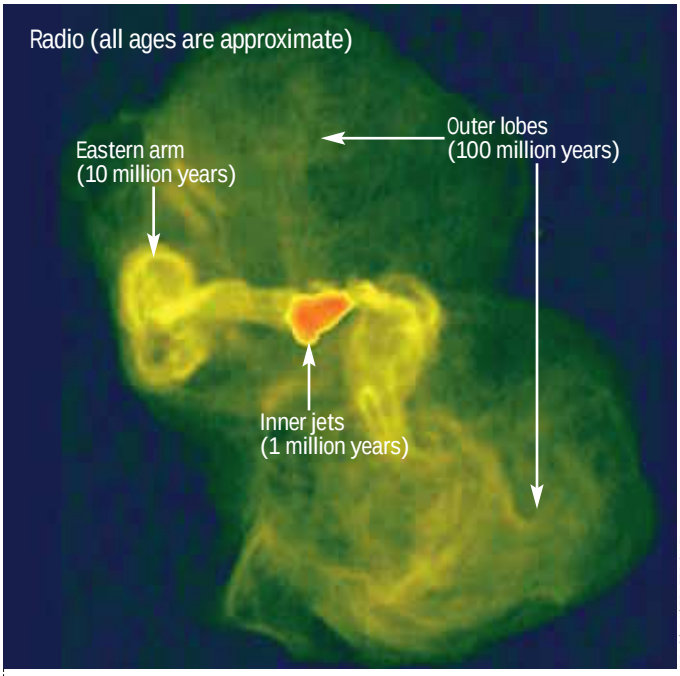
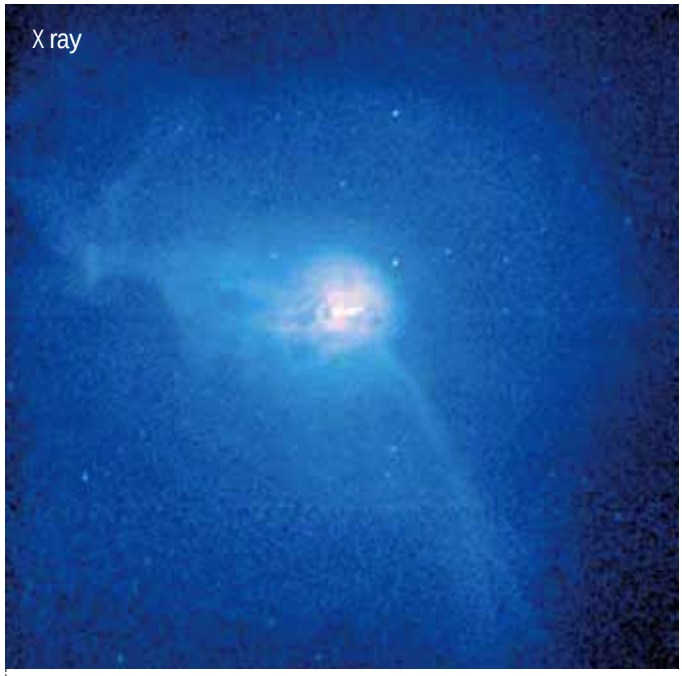


NRAO/VLA/ FRAZER OWEN

GIANT ELLIPTICAL GALAXY M87 lies in the Virgo cluster and has an active nucleus with a jet. Radio observations show shock fronts from stages of activity, each with a different age.



NASA/CXC/WILLIAM FORMAN

X-RAY OBSERVATIONS OF M87 reveal outbursts that occur roughly every 10 million years. Shock waves from the outbursts could heat the cluster gas, preventing it from cooling as much as earlier theories predicted.

"The turbulence induced by AGNs and by cluster mergers would be different," Fujita adds. "Astro-E2 can discriminate between the two patterns and should give us an answer within a year or 2."

If cooling flows exist, gas infall would be too slow (less than 72,000 mph, or 108,000 km/h) to be detected by Astro-E2 or any other instrument on the drawing board. But McNamara, Sarazin, and Boston University's Elizabeth Blanton hope to use Astro-E2 to determine gas outflows generated by radio bubbles — a measurement that's never been done before.

Some answers should come simply by watching clusters long enough to get a clearer sense of their dynamics. Forman, for example, has been granted nearly 140 hours on Chandra, mostly this year, to stare at M87. "That should tell us whether there are a few large bubbles or numerous small-scale pockets of hot gas," Begelman says.

What astronomers really need, says Nulsen, is a survey that can help resolve issues such as the number of clusters with bubbles and the number with shocks. Shocks are hard to see because they move faster than bubbles and are fainter. A survey, accordingly, will require large chunks of observing time, Nulsen admits. "That means we need clever ways of doing it."

Knowledge about clusters, moreover, can inform our understanding of galaxy formation in general, says Sarazin. "Cooling flows are a present-day analogy to the formation of large galaxies in the early universe." Clusters, being comparatively nearby, let us study many of the same physical processes in greater detail closer to home.

Of these processes, cooling looms large. If the original cooling-flow picture were correct, says Mark Voit of Michigan State University, "galaxies in the middle of clusters would keep getting brighter and brighter." But galaxies appear limited in both size and brightness, depending on whether they can obtain the cold gas that fuels star formation. The same phenomenon that cuts off star formation in clusters also cuts off the luminosity of galaxies, adds Voit.

"In fact," he says, "many big problems relating to clusters and galaxies are converging on the same question: What process regulates cooling?" Astronomers don't yet have firm answers, but just a year from now, the picture should be clearer.

ONLINE EXTRA See galaxy clusters collide and other computer-simulated flows at www.astronomy.com/toc

Cycle of the Sun

Every 11 years, the Sun's magnetic field bottoms out, reverses, and rebuilds. Scientists are beginning to understand why. /// BY GERRY BYRNE

The Sun's 11-year activity cycle is the closest thing to seasons our star has. At the cycle's peak, the Sun sports a legion of sunspots, frequently hosts the solar system's largest explosions, and often hurls billion-ton clouds of charged particles into space.

Although skywatchers associate these events with great displays of the northern lights, the active Sun also threatens astronauts and spacecraft, wreaks havoc with radio communication, and damages transformers regulating electrical power here on Earth.

At about the same time as the Sun seems to be throwing a temper tantrum, its magnetic field flips from one orientation to the exact opposite: North becomes south, and south becomes north. The process works haltingly and may occur at a different rate in the Sun's northern and southern hemispheres, but eventually, the new configuration locks into place as the Sun's most violent activity tapers off.

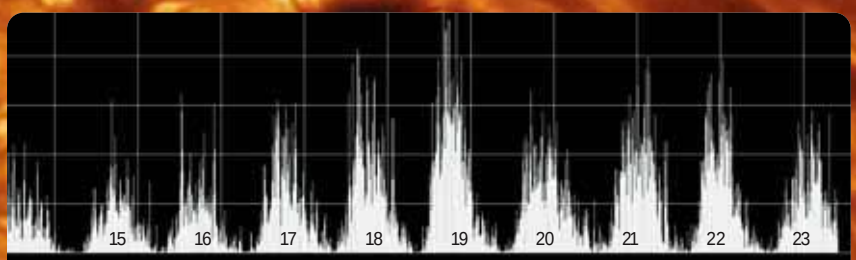
Solar scientists monitoring the Sun during the current cycle, dubbed cycle 23 and drawing to a close sometime next year, have identified connections between our star's peak activity and its recurrent magnetic flip-flop. They say massive, fast-moving gas clouds called coronal mass ejections help sweep away the old magnetic field to make room for the new.

But scientists agree cycle 23 is peculiar compared with the three that came before it. This time, for example, the Sun's field flip was unusually sluggish — the south pole switched 9 months after the north. Ultimately, explaining the solar cycle involves a better understanding of how the Sun's interior works.

Mausumi Dikpati, a solar physicist at the High Altitude Observatory in Boulder, Colorado, thinks she knows at least part of the story. She and her colleagues have worked out a model that accounts for much of the Sun's most recent behavior, and they believe it may be able to forecast solar activity up to 20 years out.

RISING BUBBLES AND LIGHT BRIDGES stand in relief when viewed near the Sun's limb. The light bridge at top left arcs more than 310 miles (500 km) above the floor of a sunspot. Hundreds of bubble-like granules, each about 620 miles (1,000 km) across, rocket out of the interior and overshoot the surface, giving the Sun a cobblestone-like texture.

SST



A RISE AND FALL in the number of spots on the Sun was astronomers' first clue to a solar activity cycle. Sunspot maximum brings more flares and enhanced solar X-ray and radio emission. The current cycle, the 23rd recognized by solar scientists, will draw to a close with sunspot minimum sometime in 2006. DAVID HATHAWAY, NASA

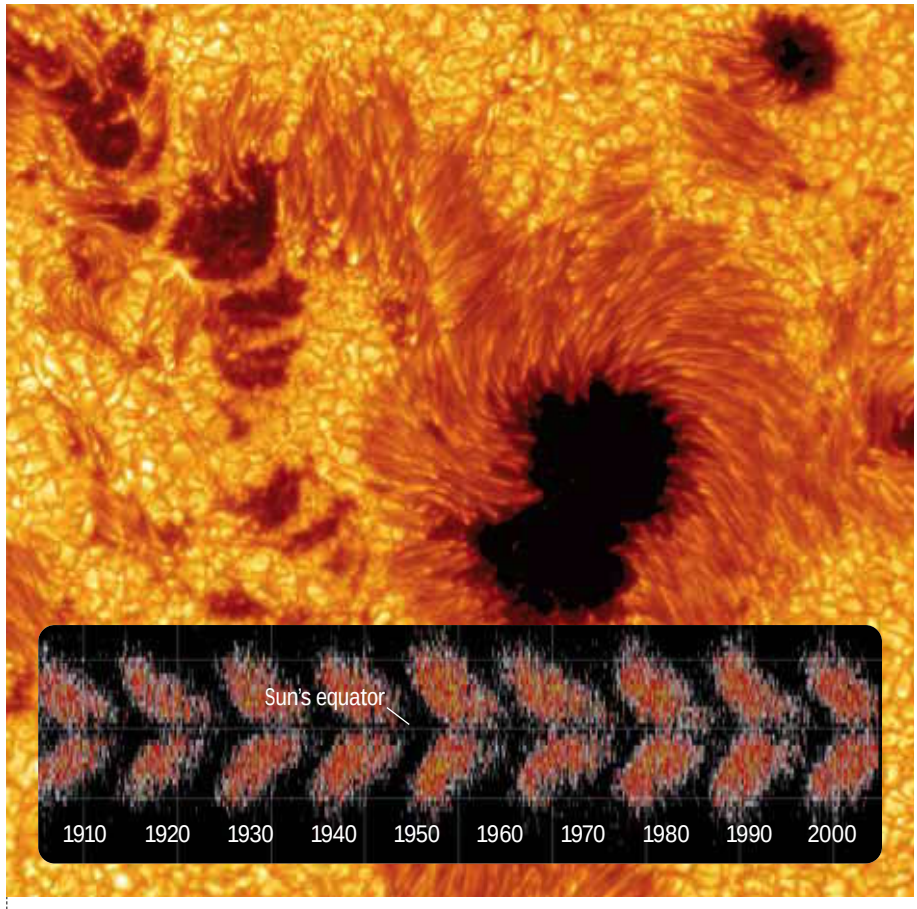
Spotted Sun

Scientists agree sunspots are visible evidence of locally concentrated magnetic fields. They believe each spot starts its life thousands of miles beneath the seething surface, where a small part of the Sun's global magnetic field becomes coiled and twisted. This action intensifies the field's stored energy like twisting a rubber band, and the strengthened field rises toward the surface as a potent loop of magnetic flux.

The magnetic loop can be 3,000 times stronger than the solar average by the time it emerges on the Sun's surface. A sunspot forms on each side of the loop's "footprints," where it burrows back into the Sun. The spot's super-strong magnetic field allows it to remain intact despite being surrounded by roiling blobs of hotter plasma.

Solar physicists think they understand the broad picture, but the detailed mechanisms at work — and, in particular, how they explain what we observe on the Sun — remain elusive. Why do sunspots grow in size and number toward the peak of the solar cycle? Why do they appear at the Sun's middle latitudes as each new cycle begins, and then migrate toward the equator as it progresses? The sunspot cycle can be as brief as 9 years or as long as 14, so what controls the timing? And just how does the Sun pull off its magnetic flip?

"The problem is that we are not able to observe the magnetic field at its origin," says Roger Ulrich, an astronomer at the University of California at Los Angeles. He uses the 50-yard (45-meter) solar-tower telescope on Mount Wilson in California to map the Sun's surface magnetism. "It's like we're looking at the tail on the surface," Ulrich explains, "but deep in the interior is this mother lode … a big, strong magnetic field of some sort. And that's where the real power of the cycle is, we think."



GRAPH: DAVID HATHAWAY/NASA; BACKGROUND: SST

SUNSPOTS APPEAR in different locations during the course of a solar cycle. Near the start of a cycle, spots first form in the Sun's middle latitudes and then appear closer to the equator as the cycle progresses. Mapping the area of the Sun blemished by sunspots produces a characteristic "butterfly" shape that repeats from cycle to cycle.

What lies beneath

In the 1970s, a tool emerged that held the promise of revealing what's under the Sun's skin. Astronomers could peer inside our star by tracking sound waves in much the same way geologists use seismic waves to probe Earth's structure. In fact, the name of this new field of study is helioseismology.

Millions of distinct, resonating sound waves make their presence known by slight Doppler shifts in light emitted at the Sun's surface. Light is shifted to the blue when the gas rises, to the red when it falls back. The sound waves give solar physicists a high-resolution probe of temperature, chemical composition, and motion down to the Sun's core.

The Sun's visible surface, called the photosphere, is the top of its turbulent convection zone. This region extends to a depth of about 124,000 miles (200,000 kilometers) — roughly half the distance between Earth and the Moon — and accounts for 28 percent of the Sun's radius.

In the convection zone, energy travels through the wholesale motion of plasma: Hotter gas rises to the surface, cooler gas falls toward the center. In time-lapse images, the Sun's surface looks like a boiling liquid. Texas-size convection cells called granules bubble up to the photosphere where astronomers observe them. Granules travel upward at speeds of around 1,000 mph (1,600 km/h) and dissipate within minutes. They emerge hot and bright, but cool and darken rapidly as they give up their energy. Once cooled, granule gases fall back into the Sun to be heated again.

Beneath the convection zone, the Sun's turbulence calms: Rising and falling pockets of gas cease being the most efficient way to move energy. Instead, energy travels by radiation in this region, called the radiative zone. Here, gases absorb energetic gamma rays streaming from the Sun's core and reradiate them in random directions and at lower energy. Each of the newly emitted photons may be absorbed and reradiated many times, so the energy of a given photon may ricochet through the radiative zone for hundreds of thousands of years before finding its way out.

Ultimately, all of the Sun's energy comes from thermonuclear reactions in its core, which occupies the innermost 25 percent of its radius. At the center, the density is some 8 times greater than gold and the temperature peaks at 15.6 million kelvins.

In this environment, hydrogen nuclei move so fast that they bind together during

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ASTRONOMY: ROEN KELLY

Peeling the Sun's layers

Coronal mass ejection
Billion-ton-clouds of charged particles leave the Sun moving at millions of miles per hour.

Global magnetic field lines
The Sun's global magnetic field is about 10 times more powerful than Earth's. Field lines exit the Sun at the positive pole and enter at the negative pole.

Core
This is the Sun's energy source, where hydrogen fuses into helium.

Inner magnetic field lines
Magnetic field lines are pulled into an east-west rotation and become twisted as the lines rotate faster at the equator and slower at the poles.

Radiative zone
Energy moves by radiation.

Convection zone
Energy moves through rising and falling cells of gas.

Tachocline
The Sun spins like a solid body below the tachocline, and like a fluid above. Intense shear here helps create the Sun's magnetic field.

Photosphere
This is the Sun's visible surface.

Meridional flow
A current of plasma that acts as a conveyor belt in the convection zone.

Corona
This is the Sun's outer atmosphere and source of the solar wind, a thin gas that extends through the solar system.

Sunspots
Dark spots mark where amplified magnetic fields anchored far within the Sun break through the surface. Carried by the deep meridional flow, sunspot fields emerge closer to the equator as the solar cycle progresses.

Flare
Energy stored in magnetic fields creates titanic explosions.

Prominence
Magnetic fields suspend an arch of gas far above the Sun's surface.

Leftover sunspot fields
When sunspots fade away, they usually leave behind a weak magnetic imprint of opposite polarity to that of the Sun's global field at the cycle's start. The surface meridional flow brings these remnants to both poles, where they accumulate and help reverse the global field

SOLAR SCIENTISTS' UNDERSTANDING of what makes the Sun tick has improved dramatically over the last decade. This is due in large part to advances in helioseismology, which probes the solar interior using sound waves that ripple throughout the Sun. Near the surface, a meridional flow moves sunspot leftovers toward the Sun's poles. Of opposite polarity to the Sun's global field, these remnant fields accumulate at the poles and force our star's magnetic flip. The same flow pulls the fields deep into the Sun — to the tachocline at the base of the convection zone — where they will be amplified to provide sunspots for the following solar cycle.

collisions, forming helium and releasing a flood of high-energy gamma rays. The Sun has been consuming itself in this way for at least 4.6 billion years, and it will continue to do so for a similar length of time.

Spin cycle

Helioseismology not only clarified the Sun's internal structure, it revealed how solar gases move beneath the surface. In both northern and southern hemispheres, rivers of plasma flow east and west, much like Earth's trade winds. Data from the Solar and Heliospheric Observatory (SOHO) suggest high-latitude jet streams ring the Sun's north and south poles.

A leisurely stream called the meridional flow carries plasma north and south from the equator to the poles. This current has an average speed of 45 mph (70 km/h), which is about 100 times slower than the surface rotation. At this rate, it takes a little more than a year to travel from equator to pole. SOHO measurements show the entire solar surface, to a depth of 15,000 miles (24,000 km), participates in this flow.

In the 19th century, careful tracking of sunspots at different solar latitudes established the solar surface does not rotate like a solid body. Instead, it spins fastest at the equator (25 days) and slowest at the poles (thought to be about 36 days). But SOHO and ground-based studies show this differential rotation comes to a halt at the base of the convection zone. The Sun rotates like a solid object once every 27 days throughout its radiative zone and, possibly, its core.

Shear occurs in a thin layer between the convection and radiative zones where the Sun's rotation style changes dramatically. Solar physicists call this transition region the tachocline. Although the tachocline is remarkably thin — it's just 2 percent of the Sun's radius — this region is now thought to be the site of the solar dynamo, the place where the Sun generates its magnetic field.

Sunspot walks and pole flips

Until the 1990s, models of the solar dynamo involved two basic mechanisms. One used the convective zone's differential rotation to stretch and strengthen each cycle's new, predominantly polar magnetic field and wrap it around the Sun. The other relied on differential rotation to twist rising tubes of magnetic flux and strengthen them to make sunspots, as well as to regenerate the new global, north-south field that emerges at the peak of each cycle. As helioseismology blossomed, and astronomers better understood what was happening beneath the solar surface, it became clear that something was missing.

That something, says Dikpati, is part of the meridional flow. "The flow must form a closed loop because we do not see any pile-up of material at the poles, so it must have a return flow at the base of the convection zone," she says.

At the poles, Dikpati reasons, the meridional flow dives toward the base of the convection zone and then streams toward the equator, where it rises to the surface. Plasma deep in the convection zone is a million times denser than on the surface, so the equatorward flow moves at a crawl — less than 5 mph. At this rate, the deep meridional conveyor needs about 20 years to transport material from the poles to the equator.

Sunspot groups first form at middle latitudes in both hemispheres and drift toward the equator throughout each cycle. Dikpati argues the return flow drives this equatorward migration.

Magnetic fields at the base of the convection zone strengthen until they become buoyant and float up to the Sun's surface, where they form sunspots. But the fields remain rooted deep in the convection zone, where they intensify. So, as the return flow slowly chugs toward the equator, sunspot groups follow.

Sunspots remain intact for only a few solar rotations. But as their intense fields weaken, they become unplugged from their deep source and susceptible to the meridional flow on the surface. These weak magnetic leftovers have polarities opposite the Sun's magnetic field at the start of the cycle. The meridional flow carries these fields toward the poles, in the opposite direction of sunspots.

Once at the poles, the conveyor drags the leftover fields to the bottom of the convection zone, where shear in the tachocline stretches and intensifies them. These fields accumulate and strengthen as solar activity rises, and, eventually, they become strong enough to force the Sun's magnetic flip.

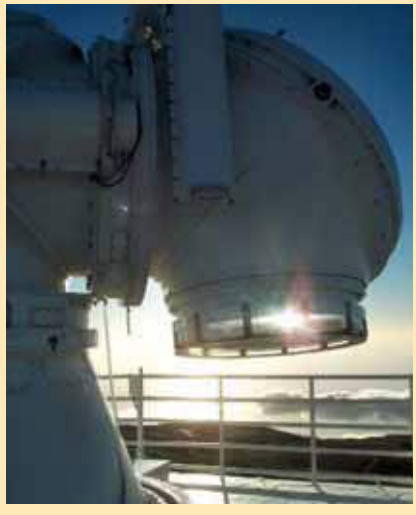
/// SUN SPEAK

- Solar dynamo: The process by which the Sun transforms mechanical energy into a magnetic field
- Meridional flow: Motion of gas from the Sun's equator to its poles
- Tachocline: The layer at the base of the convection zone where the Sun's rotation starts becoming more uniform; gas flows in this region experience shear in this sudden change

/// EYE ON THE SUN

The Swedish 1-meter Solar Telescope (SST) on La Palma in the Canary Islands is the largest solar telescope in Europe, and second only to the McMath-Pierce Telescope at Arizona's Kitt Peak National Observatory. The SST can resolve solar features just 45 miles (70 km) wide, allowing astronomers to view smaller details than ever before possible.

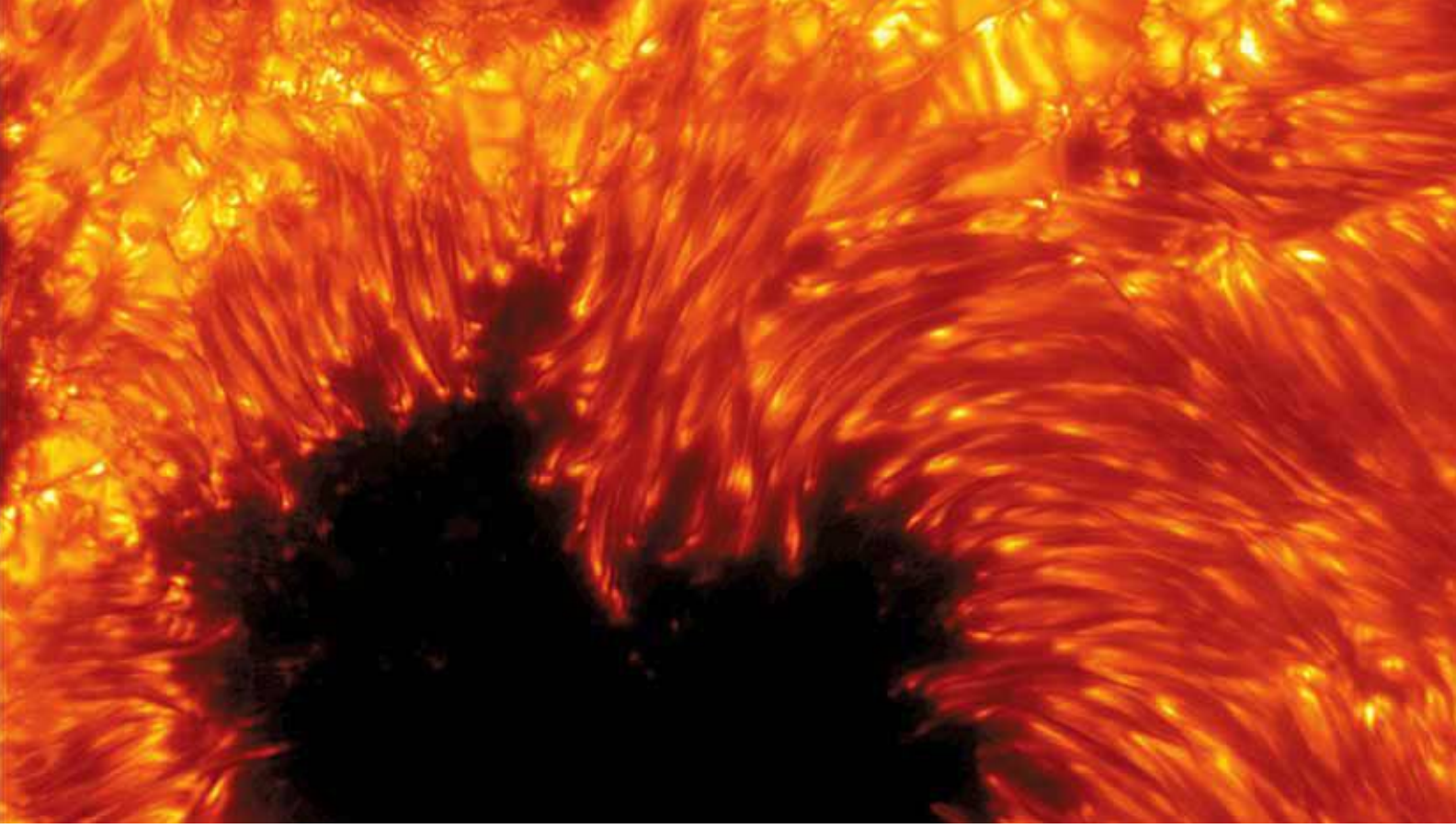
It accomplishes this feat through a combination of adaptive optics and digital image processing. The SST is the first solar telescope designed to use an adaptive mirror, which self-corrects 1,000 times a second for blurring caused by Earth's atmosphere. SST images have revealed new structures, such as dark cores and helical twists in the filaments that surround sunspots. SST images in this article are shown in false color; all were taken in blue light at a wavelength of 430 nanometers. — *Francis Reddy*



DAN KISELMAN, SST

THE SUN GLINTS sideways through the Swedish Solar Telescope's 1-meter lens.

SST



THEORISTS ARE STILL TRYING to understand the bright filaments surrounding a sunspot's core. Each filament contains a magnetic field and flowing gas, but a dark thread — presumably cooler gas — runs its length. One suggestion: a cylinder with hot walls and a cool interior.

But can it handle the truth?

Dikpati ran the model to see if it could highlight why cycle 23's reversal was so peculiar. Her team found the Sun's polar fields were stronger than in previous cycles, and the leftover fields from decayed sunspots were weaker.

Also, observations indicate the meridional flow slowed down. So to force a magnetic flip, the process needed more flux than normal to cancel out the existing polarity, and the mechanism to bring this flux to the poles fell down on the job.

The scientists also identified an eddy-like current in the northern hemisphere's meridional flow that helped pull chunks of the strong northern field deeper into the convection layer. So, despite their weakness, the leftover fields had less to overcome in the north and did the job faster there than in the southern hemisphere.

Unfortunately, a key requirement of Dikpati's model is detailed knowledge of the meridional flow. She has only 8 years of satellite records to draw on, and admits that to do the job properly, she needs data over twice as long a period. She is now turning to ground-based helioseismic measurements gathered over the past 2 decades at Mount Wilson to fill the gap.

Steve Tobias, an astrophysicist at the University of Leeds in England, remains skeptical about the importance of the meridional flow. "I think it's a promising direction. I don't think [Dikpati's team has] pinned down the cause of what's happening, although I think meridional flow could play a role," he says. "It's got to be a much weaker flow the deeper down you get because of the huge density contrasts. It's hard to say if the flows needed for such a model to work are actually there."

"She may well be right, but it will be a long time before we're sure," says Eugene Parker of the University of Chicago, an authority on the effects of magnetic fields around the Sun and planets. "You are dealing with something like meteorology on the Sun, and it's a comparable problem to forecasting weather on Earth. Progress in 10 years will be substantial, but that doesn't mean we'll have the problem solved."

David Hathaway, a solar physicist at NASA's Marshall Space Flight Center in Huntsville, Alabama, is a strong supporter of Dikpati's approach. He agrees scientists need more information about flow rates at the base of the convection zone, and he thinks they may get it sooner than many believe. NASA's Solar Dynamics Observatory, slated for a 2008 launch, will carry a helioseismic instrument that may be sensitive enough to clock the speed of that return flow.

With each solar cycle, scientists try to anticipate what the Sun will do the next time. Dikpati says predictions for cycle 23 were way off because scientists assumed the previous cycle's polar field was the sole determining factor of the maximum that followed. "That cannot be, because it takes between 17 and 22 years to bring the polar field down to the shear layer … where the sunspots are generated," she says.

At any one time, magnetic relics of three or four previous solar cycles may be embedded in the Sun's conveyor belt, each waiting their turn to be regenerated as a fresh cycle. In essence, the Sun has a magnetic memory, and one day, Dikpati says, forecasters will estimate these relic fields to predict the strength of forthcoming cycles.

To validate her model, Dikpati plans to reconstruct the past 11 solar cycles. After that, she says, she'll be ready to examine one of the Sun's deepest mysteries: the Maunder minimum, a 70-year period centered on 1670 when sunspots all but disappeared.

ONLINE EXTRA Learn about upcoming solar space missions at www.astronomy.com/toc

Can astronomers learn the origin and fate of the universe by examining stars next door? /// BY STEVE NADIS

Neighborhood

The Internet enables couch potatoes to explore the world without leaving their ergonomic swivel chairs. Contemporary astronomers find themselves in a similar position: They can probe key questions in cosmology by studying stars in our own neighborhood, the Milky Way Galaxy. It's another way of probing the distant past — call it cosmology at zero redshift — that can furnish information unattainable through the more traditional cosmological practice of peering far back in time to the universe's edge.

The trick in doing "cosmology with stars," as Michigan State University astronomer Timothy Beers puts it, is to choose old stars lying on the Milky Way's fringe, or "halo," an area far removed from the star-forming regions in the galactic disk. These stellar fossils may be 13 billion years old or more, and thus contain clues about the mix of elements in the early universe. The relative abundance of those elements can tell us about the nature of the earliest stars, the environment in which they were spawned, and the products of the first explosive supernovae that ended their lives.

Finding old stars is just part of the game. The other trick is locating stars whose spectra betray the presence of thorium and uranium — radioactive elements that decay over extremely long time spans. Astronomers can then do something similar to carbon-14 dating, used so successfully in geology and archaeology, although the astronomical technique must be applied to samples thousands of light-years away that decay over billions of years instead of thousands. This strategy could help pin down the ages of ancient stars, while setting lower limits on the ages of the galaxy and universe.

"We'd like to be able to say, 'Here's what happened in the first billion years,'" Beers says. "Right now, much of that story is uncalibrated, but we may soon be able to attach a clock to it." Using the star-dating approach, called "cosmochronometry," astronomers hope to address such basic questions as: Where did the elements come from, how and when were they produced, and what were the objects that made them? "If you're interested in the origins of life," Beers says, "you need to understand the origins of the elements required for life."

Cosmochronometry has a long way to go before it can resolve fundamental issues like these. So far, age estimates derived from the technique have been crude, although advances are being made by observers, theorists, and laboratory investigators.

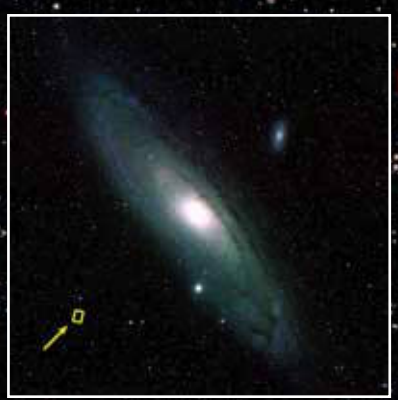
Into the halo

Observations of so-called low-metal halo stars have spurred the recent flurry of activity. Astronomers identify these stars, which include the oldest ever seen, by taking detailed spectroscopic measurements. These spectra reveal a star's "metal" content — the amount of elements heavier than helium. The idea is that immediately after the Big Bang, the only materials available for making stars were hydrogen, helium, and a trace of lithium. Beryllium and boron were produced by cosmic rays, while all heavier elements, from carbon to uranium, were produced by nuclear processes within stars.

The enrichment of the universe has proceeded gradually since the formation of the first stars. To find the oldest stars, investigators look for those with the lowest metal content. The most metal-deficient one spotted to date, HE 0107–5240, has just $\frac{1}{200,000}$ the metal content of the Sun. (That's based on the standard measure in the field: the ratio of iron to hydrogen.)

THE MILKY WAY'S HALO looks much like the Andromeda Galaxy's seen in this Hubble image. Having started to identify ancient stars in our galaxy's halo, astronomers now can learn about the early universe right here at home. ANDROMEDA'S HALO (inset), at least the part imaged by Hubble (box), lies well away from the galaxy's disk and looks nearly empty in this ground-based image. NASA, ESA, AND T. M. BROWN (STSCI) INSET: BILL SCHOENING, VANESSA HARVEY/REU PROGRAM/NOAO/AURA/NSF

secrets



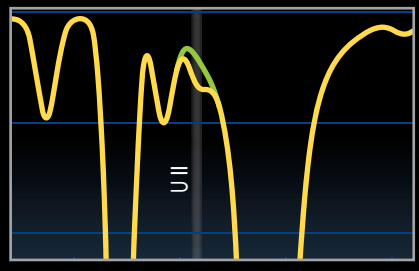
/// URANIUM BETRAYS ANCIENT HALO STAR

Uranium is the rarest of all naturally occurring elements, so it's no wonder it's difficult to find in a star's spectrum. In fact, until 2001, uranium had never been detected outside the solar system. That changed with observations of the 12th-magnitude star CS 31082–001, an extremely metal-poor object in the halo of the Milky Way Galaxy.

A team of astronomers led by Roger Cayrel of the Observatory of Paris-Meudon took a spectrum of the star with the 8.2-meter Very Large Telescope in Chile. They not only found a line of singly ionized uranium but also 14 lines of thorium, another key element in dating ancient stars. These rare elements showed up because there were relatively few other lines to contaminate the spectrum. The lack of most metals made finding these precious elements possible. *— Richard Talcott*

EUROPEAN SOUTHERN OBSERVATORY

HALO STAR CS 31082–001 (center) appears to be about 12.5 billion years old, making it one of the universe's earliest and an excellent target for cosmochronometry studies.



ASTRONOMY: RICK JOHNSON

IONIZED URANIUM (U II) shows up as a small dip in the spectrum of CS 31082–001. If the star lacked this element, the spectrum would follow the green portion of the curve.

Researchers are becoming adept at identifying elements concealed amid a thicket of spectral lines. University of Texas astronomer Christopher Sneden and his colleagues, for example, measured the abundance of 57 elements in the star CS 22892–052 — that's more elements than have been seen in any star besides the Sun. That's just one indication of how far the state of the art has advanced.

Determining the abundance of elements from a stellar spectrum is a complex art. The starting point is standard absorption spectroscopy: Atoms remove energy from light at characteristic wavelengths, leaving dark absorption lines in the spectrum. Each atom produces a distinctive pattern of lines. Astronomers rely on models of spectra for stars at a given temperature and metal abundance. "That tells you what you should see — a model version of the spectrum," explains Beers. Researchers then compare the predicted strengths of the absorption lines with those observed. From this, they deduce the amount of light removed from the spectrum and, thereby, infer an element's abundance.

Steve Nadis *is a science writer and frequent* Astronomy *contributor who lives in Cambridge, Massachusetts.*

For chronometry, the more elements that can be measured, the better, but distinct lines of thorium and uranium are especially helpful. Choosing the right radioactive isotope for your "clock" is critical, because you don't want an element that decays too quickly. Time frames are long in cosmology, and accurate measurements require sufficient quantities of the material to last billions of years. Thorium-232, with a half-life of 14.1 billion years, and uranium-238, with a half-life of 4.5 billion years, surely qualify.

In 2001, Roger Cayrel from the Observatory of Paris-Meudon, along with collaborators, unveiled the first measurements of thorium and uranium in a metal-poor star, CS 31082–001. Since then, two other stars with discernible thorium and uranium lines have been reported. "The importance of having abundances of both thorium and uranium in a single star cannot be overstated," says Sneden. Because the two elements have different decay rates, the thorium-to-uranium abundance ratio changes in a predictable way — making it a sensitive indicator of a star's age.

The general strategy is to measure the relative abundance of thorium and uranium as seen in stars today and compare that with the initial abundance ratio. Knowing the difference between these two ratios and how fast these elements decay, astronomers can easily deduce a star's age. Figuring out the initial ratio, however, is far from simple. It's tied up with questions about the origins of heavy elements — a long-standing cosmological puzzle.

Creating the elements

Astronomers have little doubt that nuclear fusion in stellar cores creates the elements carbon through iron. Elements with higher atomic numbers (30 and up) form through "neutron capture."

In this process, an atomic nucleus absorbs additional neutrons. This doesn't change the element — an element is defined solely by the number of protons in its nucleus (its atomic number). However, neutron capture is followed by beta decay, a radioactive process that converts a neutron into a proton, an electron, and an antineutrino. The electron and antineutrino are ejected from the nucleus, while the proton stays behind.

Neutron capture assumes two forms, occurring either slowly (the s-process) or rapidly (the r-process) compared with how long it takes the new nuclei to beta decay. Each process contributes roughly half the total elements.

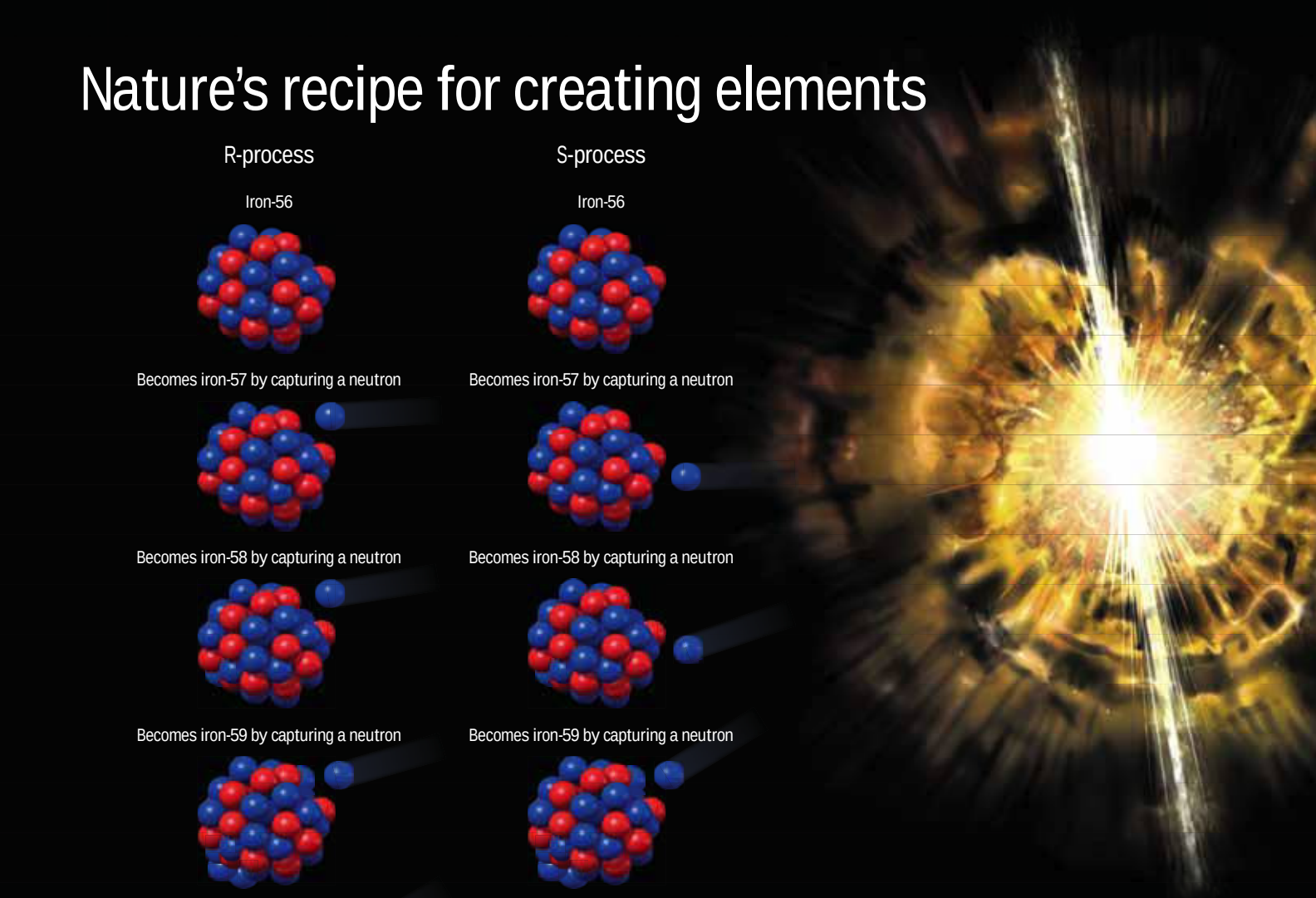
The s-process shuts off at element 83, bismuth. All heavier elements, thorium and uranium included, are made by the r-process. The r-process created the first heavier-than-iron metals in the Milky Way, so those are the ones observed in the oldest stars. S-process elements did not emerge until later in the galaxy's history.

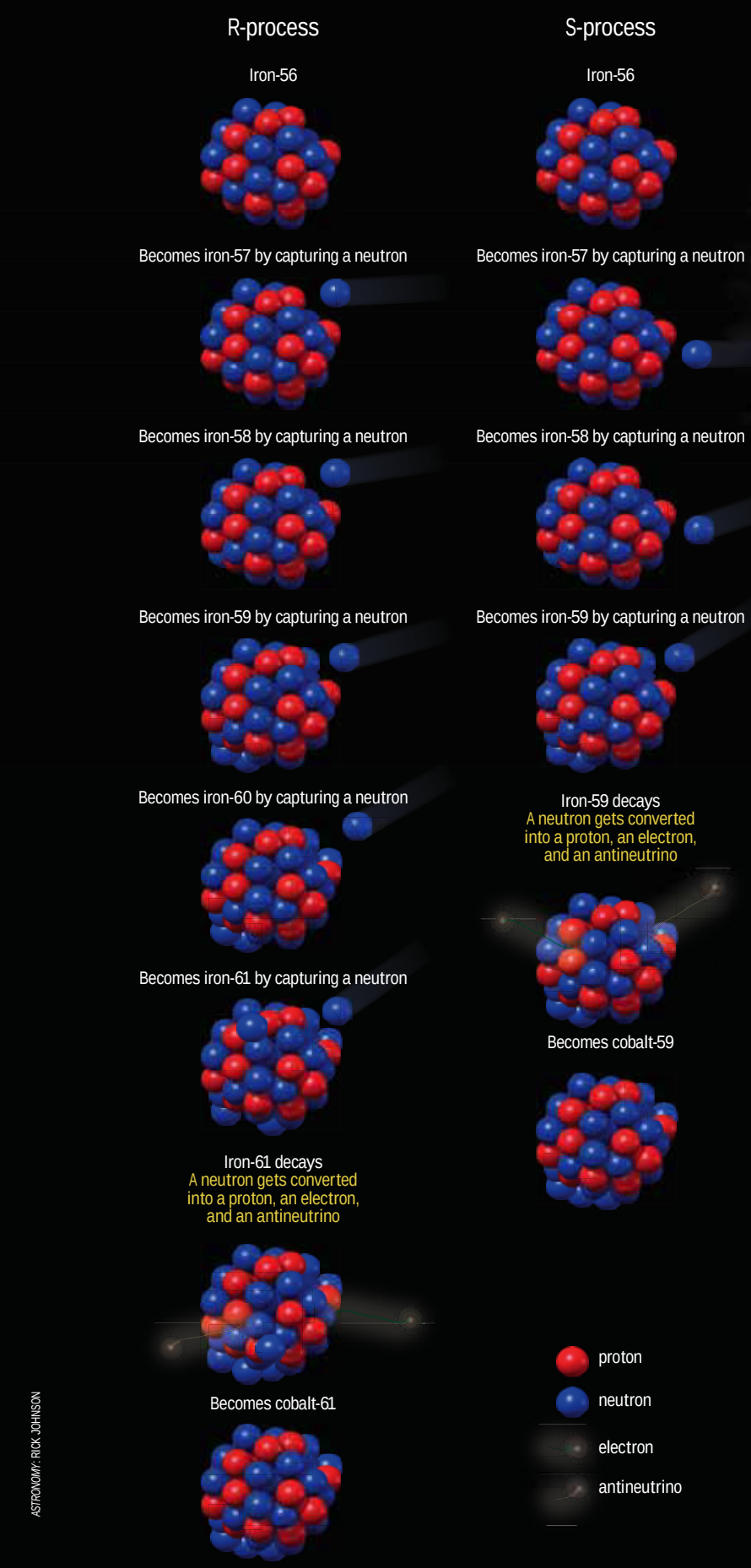
Models for the s-process work well. "That's because we're dealing with nuclei that are either stable or have long half-lives," explains University of Oklahoma astrophysicist John Cowan. "We've been able to measure their properties in the lab for decades."

The r-process, on the other hand, is shrouded in mystery. The wildly unstable nuclei that give rise to elements like uranium and thorium are so exotic, adds Michigan State physicist Hendrik Schatz, they've never been created in the lab. "We barely know anything about them."

Researchers have yet to identify the astrophysical setting where r-process elements are made. Mergers of neutron stars were once a leading candidate, but theorists now believe mergers proceed too

Nature's recipe for creating elements




R-process
Iron-56
Becomes iron-57 by capturing a neutron
Becomes iron-58 by capturing a neutron
Becomes iron-59 by capturing a neutron
Becomes iron-60 by capturing a neutron
Becomes iron-61 by capturing a neutron
Iron-61 decays
A neutron gets converted into a proton, an electron, and an antineutrino
Becomes cobalt-61
S-process
Iron-56
Becomes iron-57 by capturing a neutron
Becomes iron-58 by capturing a neutron
Becomes iron-59 by capturing a neutron
Iron-59 decays
A neutron gets converted into a proton, an electron, and an antineutrino
Becomes cobalt-59
proton
neutron
electron
antineutrino

The universe began as a pretty dull place — lots of hydrogen and helium, but little else. Things began to grow interesting after the first stars formed. These ancient ancestors of the stars we see today fused hydrogen into helium in their cores. Later, they and their offspring created more complex atoms, including carbon, oxygen, and nitrogen.

The heaviest stars forged ever more exotic elements, up to iron-56 (a nucleus containing 26 protons and 30 neutrons). But that's as far as fusion goes. Creating heavier elements requires an influx of neutrons. Let's look at how stars turn iron-56 into isotopes of cobalt. The same methods produce heavier elements as well.

Deep inside evolved stars, nuclear reactions create lots of neutrons. When iron-56 captures a neutron, it becomes iron-57. Another capture produces iron-58, and another iron-59. Each neutron capture takes about a year — so scientists dub this the s-process (for slow). Iron-57 and iron-58 are fairly stable, but iron-59 decays to cobalt-59 in a month, before it can capture another neutron.

To get past this roadblock, you need a high flux of neutrons, like that found in supernovae. Iron-59 adds one neutron to make iron-60 and a second to form iron-61. That then decays to stable cobalt-61. Scientists call this the r-process because it happens so rapidly. The same process creates the heaviest elements. — *R. T.*

ASTRONOMY: RICK JOHNSON

slowly, putting the scenario at odds with recent observations of low-metal stars.

The best guess is that the r-process occurs more commonly within supernovae, says Cowan, "but the place within a supernova cannot be pinned down because we don't know the details of the explosion." Many questions remain: What is the mass of the supernova's progenitor star? After the star collapses, triggering the explosion, where is the r-process material made and ejected? How many neutrons are needed to sustain the r-process?

Despite these quandaries, astronomers have managed to construct r-process models that work surprisingly well. To get around the explosion specifics, researchers separate their calculations from the supernova. "Essentially, we say somewhere in the universe a lot of neutrons are made," Schatz explains. "We take a seed nucleus like iron and try to guess the neutron flux and other conditions that would produce all the stable elements in the proportions seen today."

The next step is to determine exactly how much thorium and uranium the model predicts. Estimated abundances of these and other elements are used as a starting point for the chronometer.

/// OLD BONES AND AGED STARS – DATING RELICS OF THE PAST

It may surprise you that astronomers seeking the age of the oldest objects in the cosmos use the same technique as archaeologists pinpointing the age of ancient human bones. Welcome to the world of radioactive dating.

The approach works because every radioactive element decays at a set rate, known as its half-life. Gather enough atoms together, and you can say with certainty that half the existing atoms will decay in the given time.

To measure long periods, like the age of the first stars, you need a long-lived element. Astronomers use uranium-238, which decays to lead-206 with a half-life of 4.47 billion years, and thorium-232, which decays to lead-208 with a half-life of 14.1 billion years.

Archaeologists usually want to date bones thousands of years old. Carbon-14 is the perfect isotope. It decays to nitrogen-14 with a half-life of 5,730 years. — *R. T.*

AT THE GALAXY'S BIRTH, a star (left) would contain only traces of uranium and thorium. Astronomers want to find out when the star formed. Archaeologists want to learn when a human ancestor was alive. Fortunately, carbon-14 stops being absorbed by bones (right) at death.

AFTER ONE HALF-LIFE of uranium-238, the ancient star hasn't changed much in appearance. One half-life of carbon-14 has had a more noticeable effect on the bone. A graph showing the percentage of remaining atoms for each radioactive element (middle) looks exactly the same.

ANOTHER HALF-LIFE goes by and the halo star looks the same — although our solar system is forming in the galaxy's disk. The bone looks much worse for wear. Yet the radioactive elements in both still tell the same story, with just one-quarter of the original amount left.

ASTRONOMY: RICK JOHNSON

On the trail of ancient stars

Following this approach, Cayrel's team estimated the age of CS 31082–001 at 12.5 billion years, give or take 3 billion. Sneden's team arrived at an estimate of 14.2 billion years (plus or minus 3 billion) for CS 22892–052.

Of course, a star can't be older than the galaxy or universe it resides in. This means estimates derived from cosmochronometry, if credible, establish lower bounds on the age of the galaxy and universe.

Star dating offers a potential advantage because it relies on direct measurements that are independent of age calculations based on cosmic microwave background studies, like those made by the Wilkinson Microwave Anisotropy Probe (WMAP). "The answer you get from chronometry doesn't depend on the assumptions you make about cosmology," Cowan says.

So far, chronometry points to a universe that's roughly 13 to 14 billion years old — consistent with WMAP's findings and reassuring to practitioners in the field. But the point, says Harvard astronomer Lars Hernquist, is not just to get a single number like the age of the universe. "WMAP gives you precise measurements of the *average* properties of the universe, but it can't tell you how things evolved after the cosmic microwave background was released," Hernquist explains. "This approach, on the other hand, can provide the details, mapping out the history of star and galaxy formation."

Measurements of element abundance ratios in old stars, according to University of Chicago cosmologist Jason Tumlinson, provide strong clues about the size of the universe's first stars. A 2004 analysis by Tumlinson and his colleagues suggests the oldest stars known were enriched by supernovae whose progenitor stars weighed between 10 and 140 solar masses. This model fits well with both WMAP results and the latest observations of halo stars, he says.

Knowing exactly when the first stars formed, according to Hernquist, could reveal the nature of dark matter — the mysterious stuff thought to make up nearly one-quarter of the universe's mass-energy content.

Stars would have formed earlier if dark-matter particles are about as massive as a proton and move slowly (cold dark matter), whereas star formation would

have been delayed if dark matter is lighter and moves faster (warm dark matter). WMAP can't differentiate between the two scenarios, says Hernquist, but the age-dating of metal-poor stars might.

Nevertheless, chronometry cannot shed much light on questions like this until astronomers greatly reduce the method's error bars — currently an ample 3 billion years. About half the uncertainty lies on the observational side, the other half in theory, Schatz says. On the theoretical end, the biggest uncertainty remains our limited knowledge of the r-process.

The future is near

Schatz hopes to make headway through experiments at the National Superconducting Cyclotron Laboratory (NSCL), based at Michigan State University, and a more ambitious facility, the Rare Isotope Accelerator (RIA), slated for operation in 2012 at a site to be named. High-speed nuclear collisions at NSCL can produce lightweight r-process elements, but RIA's higher-intensity beam should create the majority of r-process elements. "That should put most of the r-process on a solid experimental footing," claims Schatz. Still, RIA will not create the direct progenitors of uranium and thorium. "There will still be some extrapolation," he admits, "but it will take a much smaller leap."

On the observing end, astronomers are combing the galaxy's halo for stars with ever lower metallicity, ideally ones that also contain strong lines of uranium and thorium. Most spectroscopic measurements to date have been in the visible spectrum, but Cowan believes ultraviolet observations are critical. That's why he, Sneden, and Beers propose pointing the ultraviolet-sensitive Hubble Space Telescope at halo stars.

How accurate can chronometry get? The WMAP team claims the universe is 13.7 billion years old, accurate to within 1 percent. "I don't think we'll get close to 1-percent accuracy in the foreseeable future," says Cowan, "but there are still opportunities for dramatic improvement." To some extent, it's a question of numbers: Once the distribution of elements is known for a large population of halo stars over a broad range of metallicity, chronometry will begin to furnish reliable age estimates.

So far, researchers in the field have had limited data to work with, but Beers expects the floodgates will open soon. By the time the Sloan Digital Sky Survey (SDSS) is complete — the effort may conclude in 2005 or be extended to 2008 — he and his colleagues should have access to spectral data on 50,000 stars, 5,000 of which are likely to be ancient, low-metal ones.

What's more, Beers and others have proposed a follow-up to SDSS called the Sloan Extension for Galactic Understanding and Exploration. In 2 years, this project could revolutionize stellar astronomy by capturing spectra for 250,000 stars, including 50,000 low-metal stars.

Once astronomers have spectral measurements for thousands of halo stars at their disposal, the fun should really begin. And, more importantly, a clearer picture should emerge.

A big part of cosmology, Beers says, is figuring out what the universe is made of and where the elements came from. "The story is unsatisfying right now because it doesn't have a beginning. We want to know how all the things we see today got here." If Beers and his fellow scientists are right, answers will come from the study of metal-poor stars.

"Having nearby stars that can transport us to the early universe is a gift from nature that's almost too good to ask for," says Tumlinson. It's easy to imagine that no stars would have survived from that epoch, leaving no direct evidence for us to examine. Despite our good fortune in having these stars as neighbors, it has taken human ingenuity, rather than luck, to elicit their secrets. A

/// CRASH-TESTING ATOMIC NUCLEI

To get a better handle on cosmochronometry, scientists need to understand the r-process better. The National Superconducting Cyclotron Laboratory produces many rare r-process nuclei. The technique: Accelerate a stable nucleus to 60 percent of the speed of light and smash it into a target, which fragments the nucleus into rare isotopes. — *R. T.*

MICHIGAN STATE UNIVERSITY

THE A1900 SEPARATOR at the National Superconducting Cyclotron Laboratory creates lightweight r-process elements, helping scientists understand this vital process.

BY MARTIN RATCLIFFE AND ALISTER LING

JUNE 05

Comets cruise the dead of night while the inner planets dance in twilight. Still, gas-giant Jupiter remains the most prominent target this summer.

Mercury and Venus do the tango

Have you ever wanted to see two planets

together in a high-power field of view? Well, you get that chance June 27 around noon EDT. That's when Mercury's orbital dance brings it a mere 4' from Venus. Through a telescope, that gap covers a similar angular extent as the Moon's Mare Crisium. The pair appears less than a Moon-width apart for a few days on either side of the 27th.

The best way to find Venus during daylight is with a go-to telescope. This avoids the risk of accidentally pointing your scope at the Sun, which will cause irreversible eye damage. If you don't own a go-to scope, it's better to wait until after sunset and view the planets when they lie slightly farther apart. The tilt of Earth's axis this month brings the Northern Hemisphere its summer solstice and also causes these planets to be low in the evening sky. You may need binoculars to spy them 30 to 45 minutes after sunset.

This is the final conjunction in a series of five that began last December. The two inner planets haven't appeared this close since 1990.

If you want a last look at Saturn before it disappears behind the Sun for a couple of months, you must locate it before the sky grows completely dark. Turbulence in Earth's atmosphere will degrade the view through a telescope with each passing minute. Late in the month, Saturn joins the dancing duo of Mercury and Venus.

GEORGE LIVADARAS

A CLOSE CONJUNCTION between Mercury and Venus highlights late-June evenings, similar to this pairing in 1994.

In contrast, the gas-giant planet Jupiter is well placed for observation. It lies halfway to the zenith in the southwest as darkness falls. It is the brightest point of light in the evening sky, a steady beacon with a beige color. Compare it to the blue-white sparkle of Spica, the bright star just east of Jupiter.

You can practice your daytime search skills June 15 and 16, when Jupiter lies near the First Quarter Moon. From North America on the 15th, the planet appears 8 lunar diameters from the Moon in the 9-o'clock position relative to the lunar terminator (the straight line that divides light from dark). The next day, Jupiter lies 9° (almost the width of a fist at arm's length) away between the 2- and 3-o'clock positions. First find the planet with binoculars, then, if the sky is a transparent, deep blue, try to spot it with your naked eye.

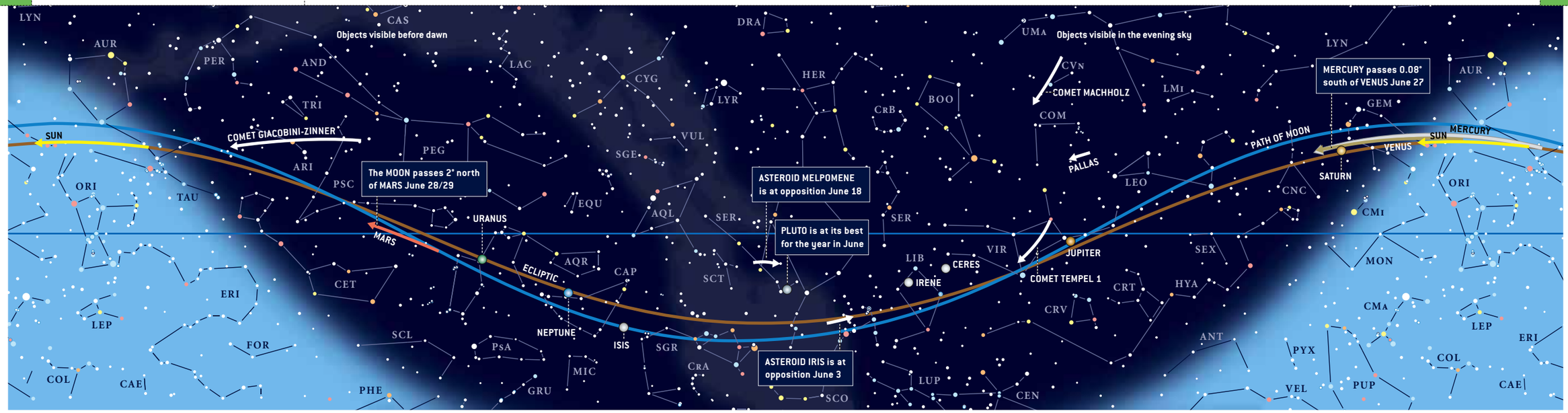
Where's Mars? It's been nearly 2 years since its last close approach. Earth is still playing catch-up in the planets' orbital race, which leaves the Red Planet rising in the east just before 2 a.m. local daylight time. Some tired all-night observers might mistake it for a nova — a star that has a massive outburst. The excitement will wane quickly with a telescopic look because Mars presents a fairly small, bland disk. In just 5 months, however, the planet will treat us to some exceptional views.

Winter's bright Comet C/2004 Q2 (Machholz) continues to be a nice target from rural locations. Follow its trek southward below the Big Dipper, using it as a guide to deep-sky objects in Canes Venatici. Another comet, 9P/Tempel 1, literally becomes a target next month when NASA slams a projectile into it (see "Fireworks on the Fourth" on page 68). By making before-and-after observations, you can witness history.

Two more comets patrol the morning sky. One of them, Comet 161P/Hartley-IRAS, provides imagers with two nice photo opportunities. First, it grazes the Pinwheel Galaxy (M33) in Triangulum. Then, it skirts the Double Cluster in Perseus.

Planets this month

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.



[09] [08] [07] [06] [05] [04] [03] [02] [01]

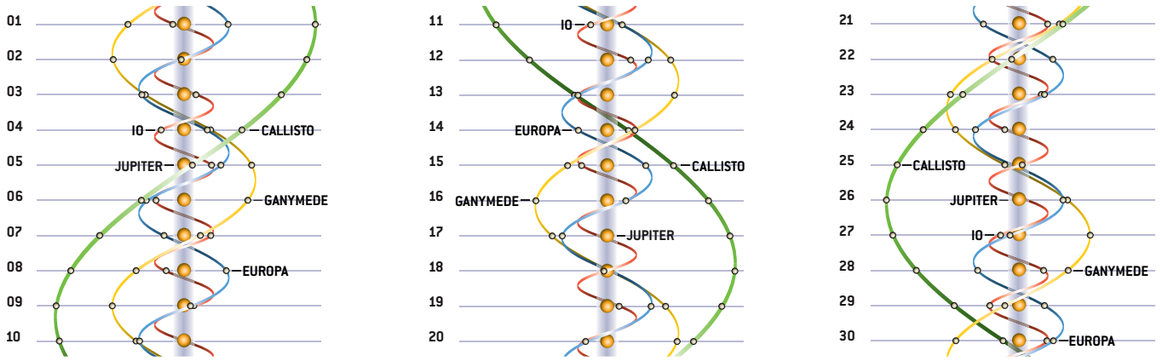
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

[30] [29] [28] [27] [26] [25] [24] [23] [22] [21] [20] [19] [18] [17] [16] [15] [14] [13] [12] [11] [10] [09] [08] [07] [06]

PLANETS	MERCURY	MERCURY	VENUS	MARS	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	June 15	June 30	June 15	June 15	June 15	June 15	June 15	June 15	June 15
Magnitude	–1.2	0.1	–3.7	0.1	–2.1	0.2	5.8	7.9	13.8
Angular size	5.5"	6.8"	10.5"	8.5"	38.6"	16.8"	3.6"	2.3"	0.1"
Illumination	86%	57%	94%	84%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.229	0.987	1.585	1.099	5.103	9.922	19.809	29.446	29.958
Distance (AU) from Sun	0.341	0.423	0.718	1.389	5.456	9.077	20.066	30.062	30.964
Right ascension (2000.0)	6h32.8m	8h20.4m	7h00.6m	0h10.8m	12h35.2m	7h52.3m	22h49.9m	21h19.3m	17h31.6m
Declination (2000.0)	25°10'	20°47'	23°59'	–1°22'	–2°18'	21°10'	–8°17'	–15°45'	–14°59'

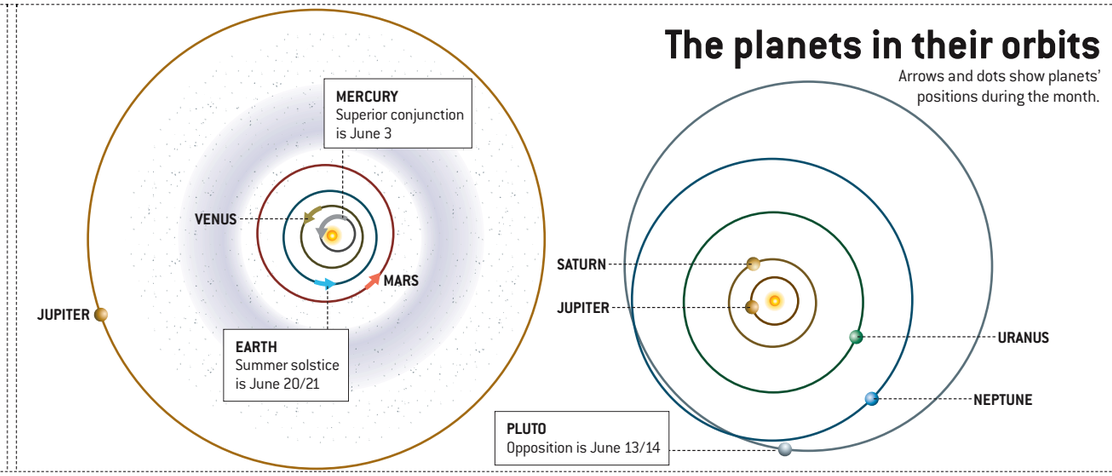
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EDT on date shown. South is at top to match the view through a telescope.



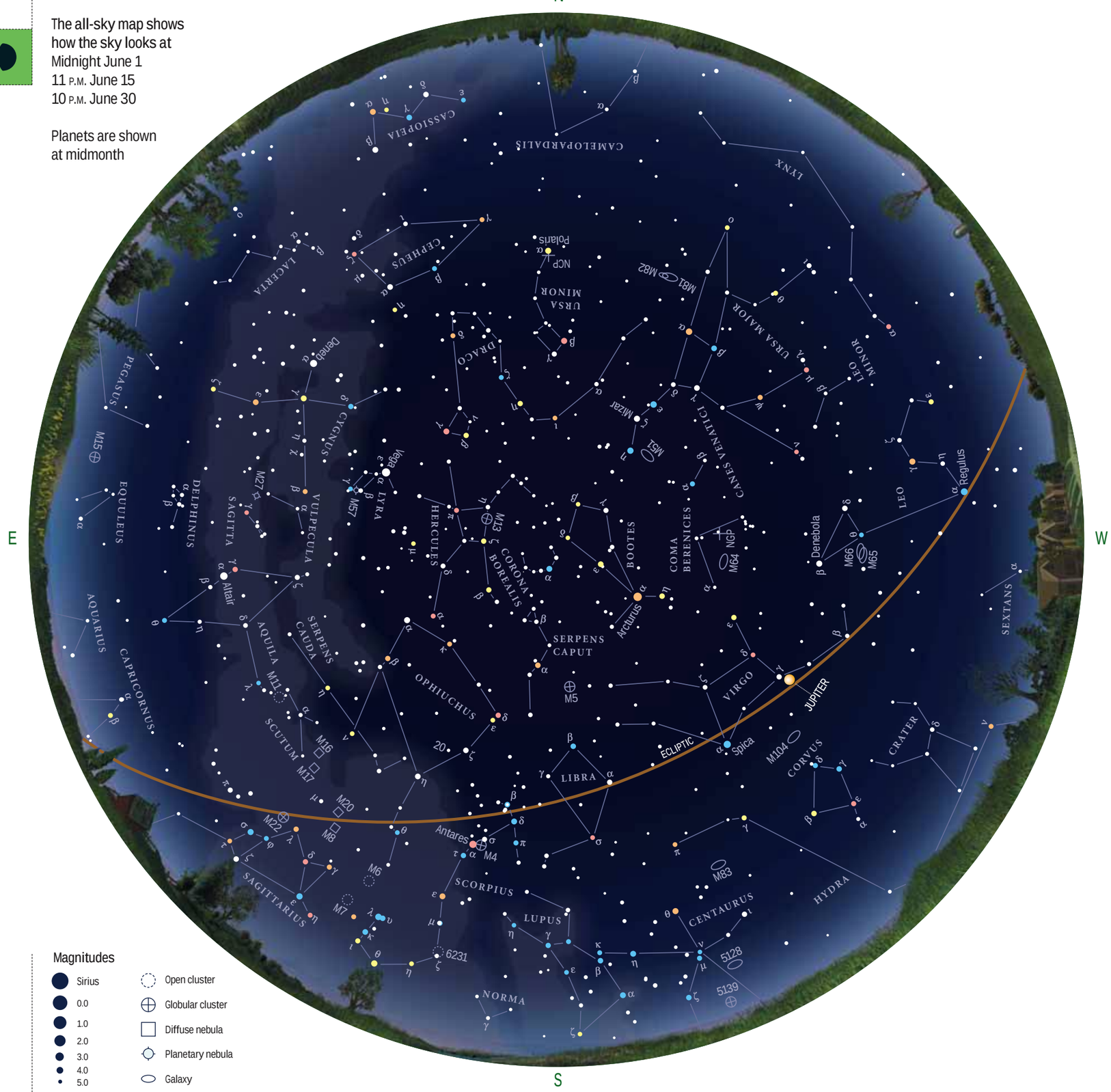
The planets in their orbits

Arrows and dots show planets' positions during the month.



The all-sky map shows how the sky looks at
Midnight June 1
11 P.M. June 15
10 P.M. June 30

Planets are shown at midmonth



Magnitudes

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

This map portrays the sky as seen near 35° north latitude at times shown in the upper left corner of the page. Located just outside the map are the four directions: north, south, east, and west. To find stars above your horizon, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

june 05

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			[01]	[02]	[03]	[04]
[05]	[06]	[07]	[08]	[09]	[10]	[11]
[12]	[13]	[14]	[15]	[16]	[17]	[18]
[19]	[20]	[21]	[22]	[23]	[24]	[25]
[26]	[27]	[28]	[29]	[30]		

03 Mercury is in superior conjunction, 5 A.M. EDT

Asteroid Iris is at opposition, 3 P.M. EDT

05 Jupiter is stationary, 6 P.M. EDT

06 New Moon is at 5:55 P.M. EDT

08 The Moon passes 4° north of Venus, 8 A.M. EDT

09 The Moon passes 5° north of Saturn, 10 P.M. EDT

11 The Moon is at apogee (251,970 miles from Earth), 2:11 A.M. EDT

13 Pluto is at opposition, 11 P.M. EDT

14 First Quarter Moon is at 9:22 P.M. EDT

16 The Moon passes 0.4° south of Jupiter, 3 A.M. EDT

18 Asteroid Melpomene is at opposition, 1 P.M. EDT

20 The Moon passes 0.7° north of Antares, 2 P.M. EDT

21 Summer solstice is at 2:46 A.M. EDT

22 Full Moon is at 12:14 A.M. EDT

23 The Moon is at perigee (223,490 miles from Earth), 7:47 A.M. EDT

Venus passes 5° south of Pollux, 8 A.M. EDT

24 Mercury passes 5° south of Pollux, 4 A.M. EDT

The Moon passes 5° south of Neptune, midnight EDT

25 Venus passes 1.3° north of Saturn, 5 P.M. EDT

26 Mercury passes 1.4° north of Saturn, 2 A.M. EDT

The Moon passes 3° south of Uranus, 3 P.M. EDT

27 Mercury passes 0.08° south of Venus, 4 P.M. EDT

28 Last Quarter Moon is at 2:23 P.M. EDT

The Moon passes 2° north of Mars, midnight EDT

For definitions of terms, visit www.astronomy.com/glossary

THE DEEP SKY

Comet C/2004 Q2 (Machholz) passes between the celestial Hunting Dogs, drawing our attention to the background star-scape and galaxy-scape.

Hunting for stars

In 1690, Johannes Hevelius introduced the constellation Canes Venatici, the hunting dogs of Boötes the Herdsman. The dog Chara lies to the west and is centered around Beta (β) Canum Venaticorum, while Alpha (α) CVn represents the canine Asterion.

Edmond Halley bestowed the name Cor Caroli, which means "Heart of Charles," on Alpha. This fine, wide pair is an easy split in small telescopes. It has half the separation (19") of Albireo in Cygnus but shows hardly any color. Can you detect the pale yellow and lilac hues that shone in the eyes of astronomers past?

If you want color, check out Y CVn, better know as "La Superba." Its prominent orange hue is a dead giveaway for a variable star. As the star fades and cools, the color shifts more to red, just like a fire's embers.

On the night of May 31, Comet C/2004 Q2 (Machholz) nearly occults La Superba. The star then glows around magnitude 9.5 and is fading slowly.

Seeking galaxies

Because comets are extended, diffuse objects, the best views come from locations far from the city. On the New Moon weekend of June 4 and 5, take the time to focus on the comet and compare it with the nearby spiral galaxy Messier 94. Both objects have bright, nearly stellar cores and round halos. But M94 appears perfectly symmetrical, while Machholz shows one side more sharply defined than the other.

Next, hop over to the bright Sunflower Galaxy (M63). Although also a spiral, M63's arms are too thin and tightly wound to be seen in typical backyard scopes.

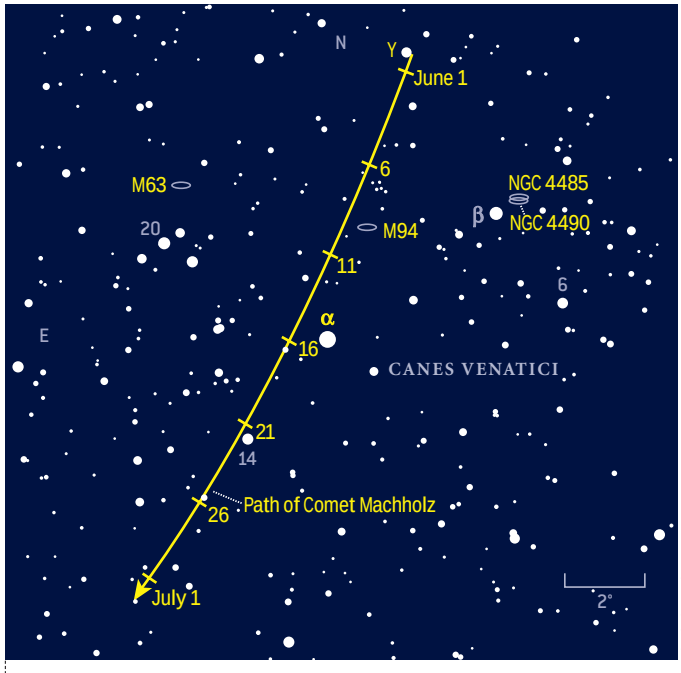
A very different sight awaits just west of Beta CVn. NGC 4485 and NGC 4490 form a pair of interacting galaxies. Long ago, the two passed close to each other, ripping off a stream of gas and dust. Now, new stars are igniting there at a furious pace. Although you won't see this level of detail at the eyepiece, you may detect hints of something different going on. Rather than having starlike nuclei, the galaxies appear more diffuse. The fainter one, NGC 4485, is fairly tough to see through a 6-inch scope.

One attraction of deep-sky observing is the voyage of imagination it launches within us. The faint smudge in the eyepiece is only the beginning. Knowing what's happening there is what makes observing exciting. A faint blip could be a supernova, a quasar, or a starburst region. Two hundred years ago, astronomers were reeling with the concept of a universe 100,000 light-years across — mere puddle-jumping for today's amateurs.

Martin Ratcliffe *is former president of the International Planetarium Society.* Alister Ling *is a meteorologist for Environment Canada.*

JOHN CHUMACK

THE SUNFLOWER GALAXY (M63) displays a bright core and tightly wound spiral arms, although the latter are hard to see in backyard scopes.

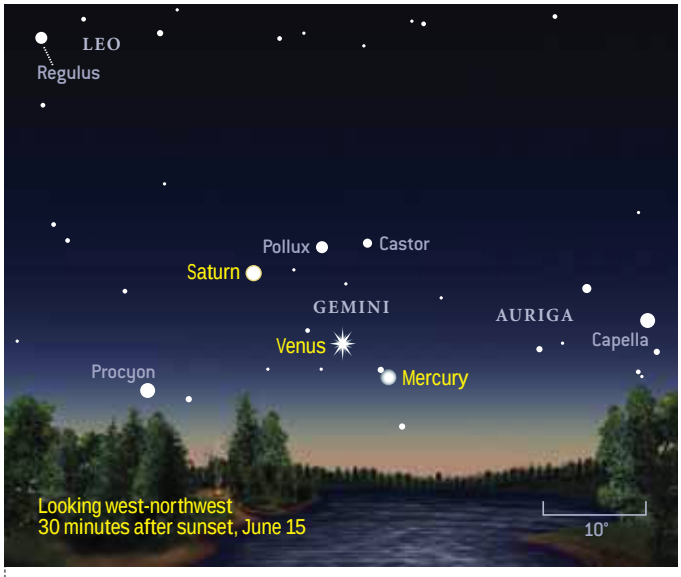


ASTRONOMY: ROEN KELLY

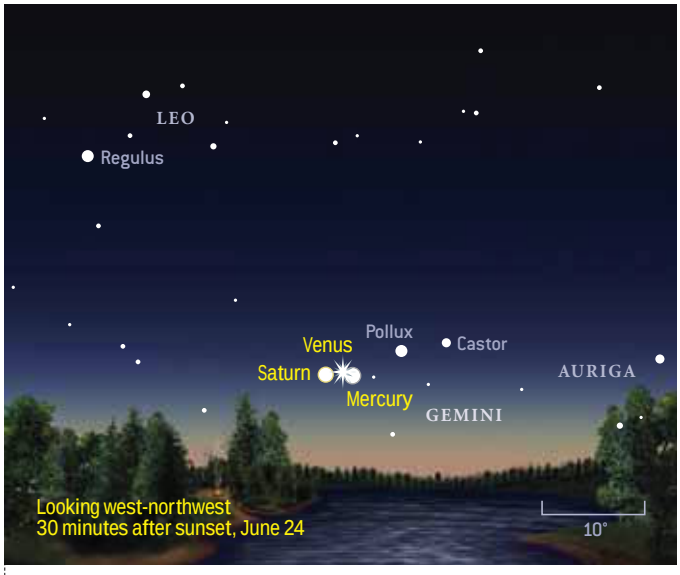
THE HUNTING DOGS of Canes Venatici and its numerous galaxies host Comet C/2004 Q2 (Machholz) this month.

THE PLANETS

June offers a backyard observer's ultimate challenge and reward: the rare opportunity to see all nine planets in one night.



MERCURY, VENUS, AND SATURN close in on one another in the early evening during mid-June.



THE THREE PLANETS appear closest together in late June, but you may need binoculars to pick them out of the twilight.

If you want to see all nine planets, you need to start right after sunset. Mercury, Venus, and Saturn congregate in the early evening sky. During a spectacular conjunction in late June, all three lie within an area no larger than 4 Moon-widths. Each night, their relative positions change.

June opens with Saturn in the western sky near the two bright stars of Gemini, Castor and Pollux. Venus lies at the lower end of Gemini, shining much brighter but setting just an hour after the Sun. As the month progresses, Venus crawls upward toward Saturn.

A slim crescent Moon joins the action at the end of June's first week. New Moon occurs June 6, so look the following night for a slim crescent to the lower right of Venus. You may need binoculars to spot our satellite against the twilight.

June 8 finds a clearly visible crescent Moon 6° above Venus. The next evening, the Moon slides between Saturn and Pollux, creating a distinctive line of four objects when you include Castor. Well below this quartet, Venus punctuates the horizon with its brilliant glow.

Venus continues its climb toward Saturn during the second week of June. By June 13, keen-eyed observers might notice Mercury to the lower right of Venus. Each succeeding evening, Mercury becomes easier to spot as it, too, climbs away from the twilight glow. Its rapid motion will have it catching up with Venus shortly.

On the 21st, Mercury and Venus stand 2° apart, just below Pollux, with Saturn to their upper left. Venus shines brightest at magnitude –3.7, then comes Mercury at –0.5 and Saturn at 0.2.

As Mercury ascends each evening, it appears slightly fainter but in a darker sky. By June 24, it lies within 1° of Venus and remains there through July 1. The two inner planets appear closest June 27, when they stand only a few arcminutes apart. They can be viewed together in the same telescopic field of view. Venus appears 11" across and shows a 91-percent-illuminated disk, contrasting nicely with Mercury's 7"-diameter disk and 60-percent-lit phase.

That same evening, Saturn lies to the lower right of the Mercury-Venus pair. Over the final few June evenings, the ringed planet descends into the twilight along with Castor and Pollux. Meanwhile, Mercury and Venus continue their dance upward through Cancer the Crab.

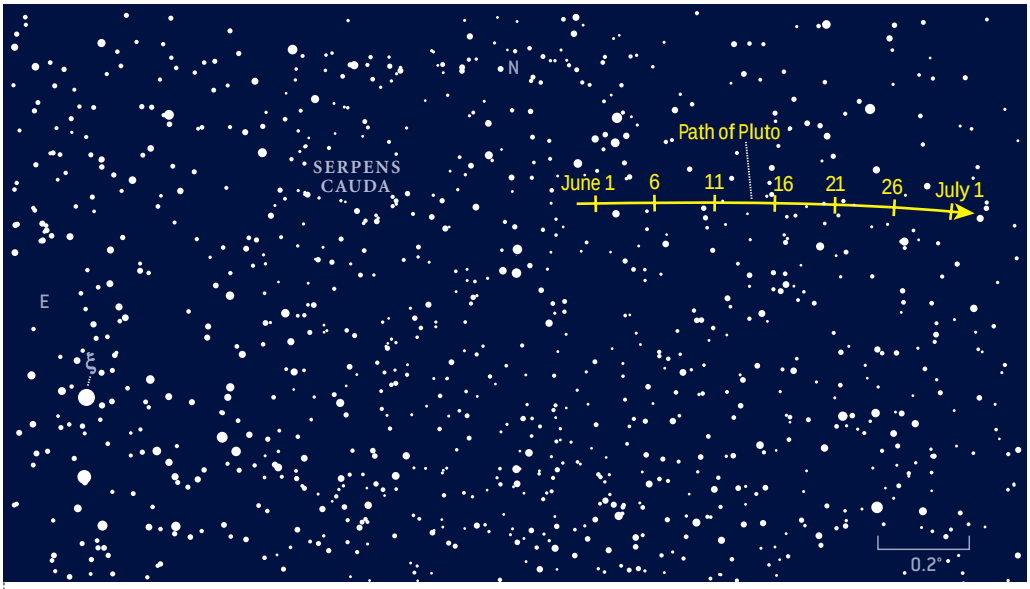
Hanging above the early evening planetary fray, Jupiter stands prominently among the stars of Virgo. On June 1, Jupiter lies due south at sunset; it moves into the southwestern sky by the 30th.

Jupiter shines at magnitude –2.1 and spans 39" during June. Given the warm nights and the planet's reasonably high evening altitude, June is ideal for viewing the atmospheric features that parade across Jupiter's disk. The most prominent features visible through backyard scopes are the two dark equatorial belts that run on either side of the planet's equator. There, on the

boundaries of these rapidly rotating regions, you can see the most detail. These features tend to disappear and then return to view as Earth's atmosphere generates turbulence. The fuzzy image in the eyepiece typically steadies for fleeting moments.

After midnight, as Jupiter approaches the western horizon, Sagittarius and Scorpius lie due south. Directly above the tail of Scorpius is sprawling Ophiuchus and its neighbor to the southeast, Serpens Cauda. Pluto lurks in the southwestern corner of this constellation, near the star Xi (ξ) Serpentis. The elusive planet lies opposite the Sun in our sky June 14, marking the best time of the year to hunt for it. Pluto glows dimly at magnitude 13.8, which means you'll need an 8-inch telescope to see it. And the more aperture you have, the better your chances.

Fortunately, the presence of 3.5-magnitude Xi Ser aids your search. At opposition, Pluto lies just 1.5° west-northwest of Xi. The finder chart (above right) shows stars down to magnitude 14.0, so you should be able to pick out which dot is Pluto. If not, sketch the stars you see in your telescope's field of view and return to the same region a night or 2 later. The "star" that has moved is Pluto.



ASTRONOMY: ROEN KELLY

ELUSIVE PLUTO lies 1.5° west-northwest of 3.5-magnitude Xi (ξ) Serpentis, making it easier than normal to glimpse through an 8-inch or larger telescope.

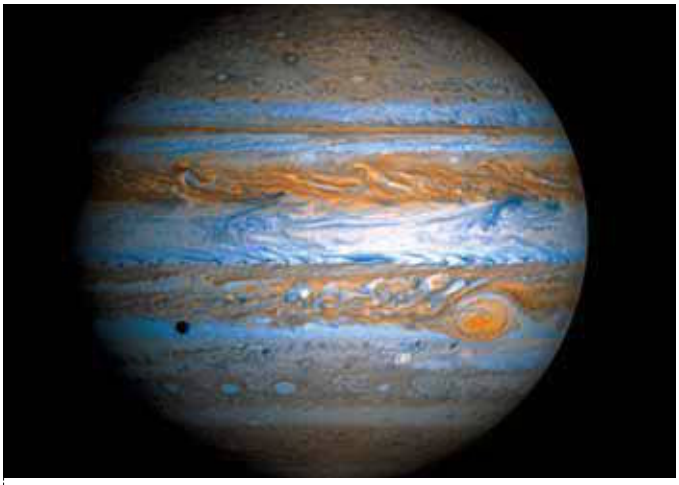
After nabbing Pluto, cast your gaze eastward toward Capricornus, the current home of Neptune. Compared with Pluto, Neptune is easy to spot. Glowing at magnitude 7.9, you'll find it 4° northeast of Theta (θ) Capricorni, the 4th-magnitude star in the north-central part of the constellation. To locate Neptune, find Iota (ι) Cap 4° east of Theta. A 5.3-magnitude star, 29 Cap lies just 2.3° northwest of Iota. Neptune spends June roughly midway between these two stars. A couple of stars brighter than Neptune lie in the same area, so be careful identifying the planet. The best way to confirm a sighting is to aim a scope in its direction. Neptune reveals its planetary status by showing a small, blue-gray disk, which measures 2.3" across.

Farther east lies Aquarius, the constellation where Uranus currently resides. This region rises around 1 a.m. local daylight time in mid-June. Uranus proves easier to see than Neptune because it's about 7 times brighter, glowing at magnitude 5.8. Although this brings it within naked-eye range, binoculars give you a better chance to spy it.

Mars, the eighth planet on view these June nights, rises about an hour after Uranus. By the break of dawn, the Red Planet stands 25° high in the east-southeast. As June closes, Mars reaches magnitude 0.0, easily the brightest object in this part of the sky except for the Moon. A waning crescent Moon passes near Mars during the final three June mornings.

Mars becomes a respectable target for telescope owners by month's end, when it reaches an angular diameter of 9". By the time it reaches opposition in November, Mars will more than double in apparent size.

The ninth and final planet has been there all night long. Simply look past your shoes to see our home planet, Earth.


NASA/JPL/SSI

JUPITER DOMINATES the mid-evening sky, easily outshining all the other planets and stars visible after Venus sets.

METEORS AND MOONS

The waxing gibbous Moon features an exceptional lunar crater, more than making up for the dearth of meteors this month.

Summer showers

The Ophiuchid meteor shower ranks among the minor showers visible throughout the year. Although best seen from southern latitudes, northerners occasionally see an Ophiuchid streak across the early-summer sky. The shower features multiple radiants that rise fairly high in the south around midnight. Rates, unfortunately, rarely climb higher than 5 meteors per hour.

On June 27, the mysterious Boötid meteor shower peaks. Typically, this shower produces no meteors. It remained dormant for more than 70 years, until a surprise outburst in 1998, when rates reached 50 to 100 meteors per hour. No one knows why it spiked then, or when it might again.

Although no big return is expected this year, it's worth keeping an eye open. Observing conditions this month should be good: The radiant lies high in the evening sky, and dark skies prevail until the Moon rises a bit after midnight June 26/27.

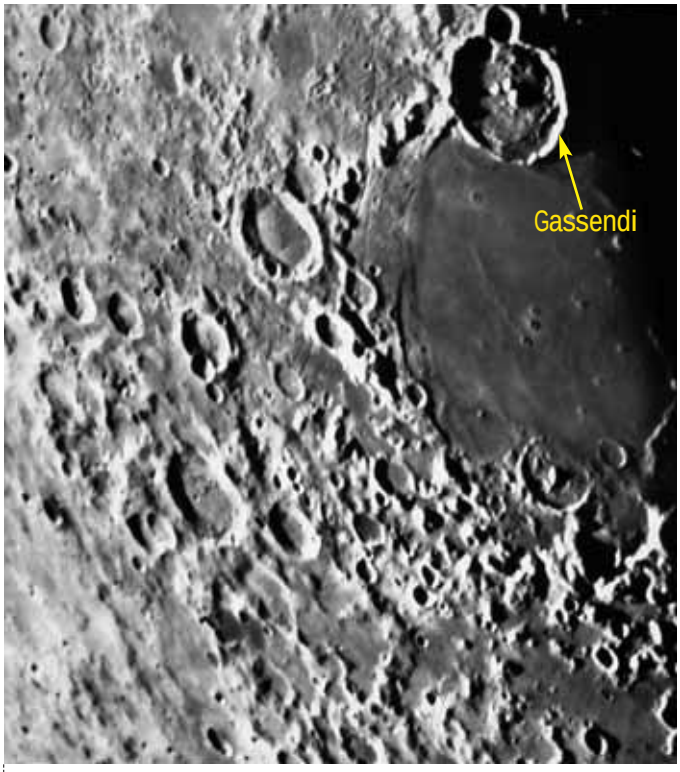
Floods of lava

Few craters on the Moon can compare with Gassendi. It lies on the northern shore of Mare Humorum, in the southwestern quadrant of the Moon. Several geologically attractive features await observers of this prominent crater. The best views of Gassendi come as the Sun rises over the region. This occurs around 11 days after New Moon, so plan to look June 17 and 18 this month.

Gassendi spans 68 miles, with the southern end of the crater wall almost completely submerged by ancient lava flows. A large, newer crater called Gassendi A breaks the prominent northern side of the main crater wall. This younger crater is more than 2 miles deep and maintains a deep shadow well after sunrise falls across the parent crater's floor.

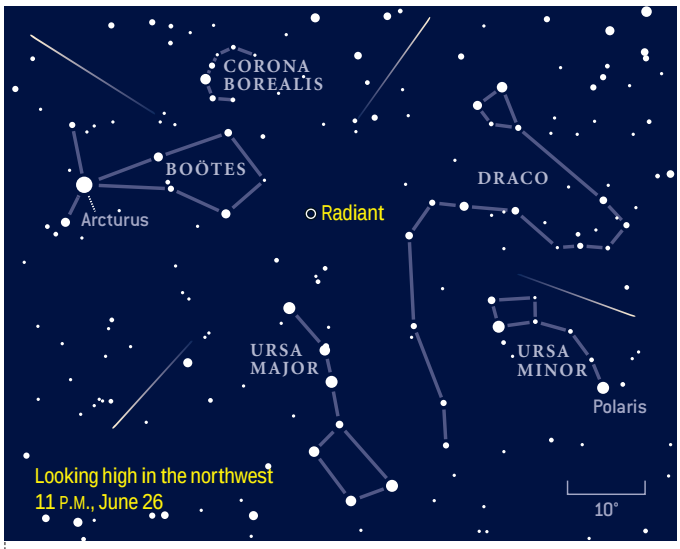
A complex central mountain range lies amid a crisscrossing network of rilles that spans Gassendi's floor. A prominent rille runs from the eastern wall to the southwest, while another connects the crater's eastern side to the central mountain range. A small telescope will show both these rilles under good seeing. Larger scopes reveal finer rilles and smaller secondary craters dotting the main crater's floor.

Notice how the terrain changes at the southern end of Gassendi, where lava has partially flooded the inner crater. The rest of the crater floor is hilly and rough, and thus much older than the lava-filled section to the south. This indicates two separate events transpired here — the upwelling of lava from Mare Humorum happened much later than the impact that created the crater.



FROM *CONSOLIDATED LUNAR ATLAS* (LPL/UA)

LUNAR CRATER GASSENDI (arrow) sits on the northern edge of Mare Humorum, whose lava flows have encroached on the southern part of the crater's floor.



ASTRONOMY: ROEN KELLY

BOÖTID METEORS may or may not show up this year, but the chance of a rare outburst makes them worth looking for.

COMETS AND ASTEROIDS

Even under the pall of city lights, you can follow the movement of the solar system's largest asteroid. Darker skies give you the chance to see four comets.

Comet cornucopia

Every now and then, we have two nice comets to compare. It's rare to have four within range of a 4-inch scope on one night, but that's the case in June. The most interesting one has to be 9P/Tempel 1 because NASA will wallop this comet with a heavy probe in early July. (See "Fireworks on the Fourth" on page 68.)

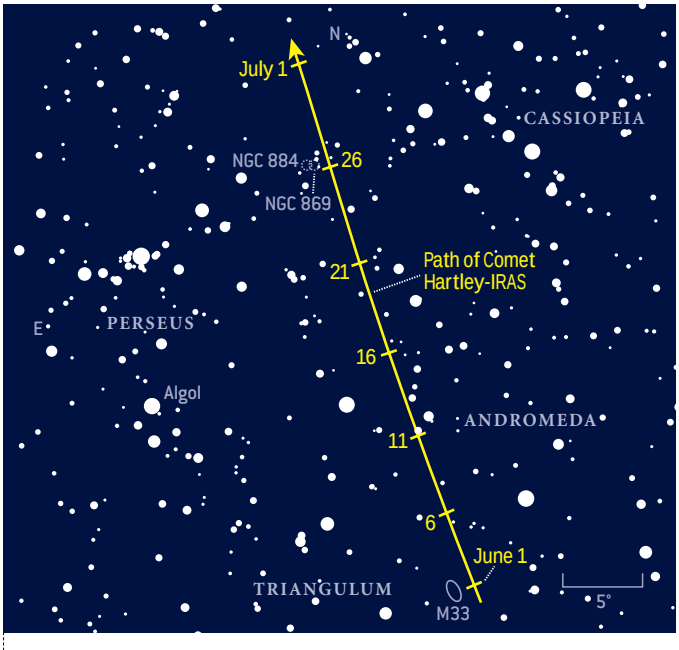
Next, we have C/2004 Q2 (Machholz), now fading gradually from its lovely mid-winter display. It helps point the way to several interesting deep-sky objects in Canes Venatici (see the finder chart on page 57).

If you went to the country to view Machholz at its peak in January, you know how much better it looked — with a longer and more obvious tail — than from the city. Urban light pollution fills the background sky with a cloak that hides subtle and faint features, and sometimes even entire comets, if you use a small scope. All of June's comets will be much easier to see from a dark site.

Getting the most out of shorter June nights means staying up until 3 a.m. local daylight time. By then, two more comets have risen in the northeast: 161P/Hartley-IRAS and 21P/Giacobini-Zinner. Glowing at 10th and 9th magnitude, respectively, these periodic comets will look similar to Machholz.

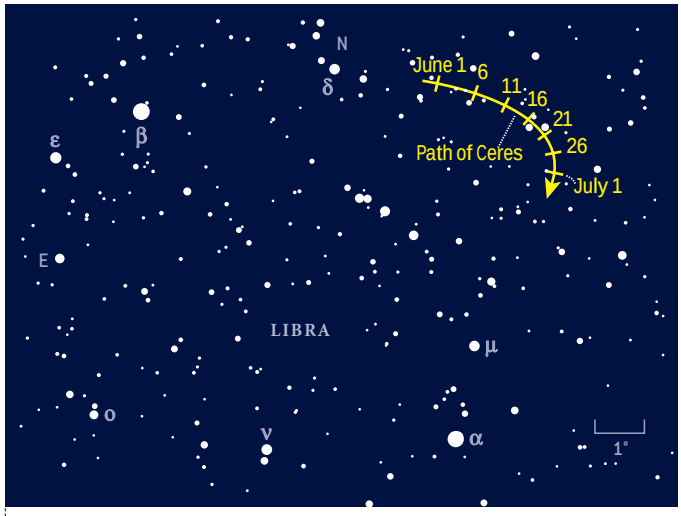
Hartley-IRAS passes within a degree of the large Pinwheel Galaxy (M33) in early June. This famous spiral has a low surface brightness that rewards patient observers with views of numerous knots, which are actually giant stellar nurseries like the Orion Nebula. By far, the easiest of these to see is NGC 604, northeast of the galaxy's center.

A nice photo opportunity occurs at midnight June 29/30, when Hartley-IRAS skims just west of NGC 869, one-half of the famed Double Cluster.



ASTRONOMY: ROEN KELLY

COMET HARTLEY-IRAS nearly slices through the halo of the Pinwheel Galaxy (M33) in early June.



ASTRONOMY: ROEN KELLY

ASTEROID CERES lies in star-rich Libra, making the 6th-magnitude object harder to see than its magnitude would have you think.

A rock among gems

Brighter objects aren't always easier to find. The asteroid 2 Pallas currently glows at 9th magnitude just north of the galaxy M85 in Coma Berenices. Most of the stars here are faint and widely spaced. Although bigger and brighter, at magnitude 7.4 in early June, asteroid 1 Ceres may be harder to spot because it lies in front of the more crowded star fields of Libra. It may not be obvious to the naked eye, but a telescope will reveal the ever-increasing number of stars as you sweep toward the central bulge of the Milky Way Galaxy.

When William Herschel coined the name "asteroid," which literally means "starlike," he wasn't kidding. A good look at the area north of Alpha (α) Librae and west of Beta (β) Lib will confirm that an asteroid is easily camouflaged by similarly bright stars. Use the chart above to zoom in on Ceres' position. Otherwise, you'll have to confirm your sighting over a couple of evenings. The asteroid's shift from one night to the next will betray the stellar imposter. Make a quick sketch of the brighter stars in the area, then come back a night or two later to see which one moved.

The universe has spawned galaxies in many shapes and sizes, and backyard scopes can let you sample all of them. /// BY RICHARD JAKIEL

Catch the galactic carnival

The universe contains billions of galaxies of every size, shape, composition, luminosity, and dynamic history. While most remain far beyond the reach of backyard telescopes, anyone with a medium-size (8-inch) or larger instrument and a dark sky can explore a sample of this great menagerie. And even small-telescope users can catch the brightest members of many galactic types.

Making sense of this galactic sideshow has challenged astronomers since the late 18th century, when William Herschel began to classify the various "nebulae" he discovered. Many of Herschel's nebulae were, in fact, true nebulae — clouds of gas and dust — not galaxies filled with billions of individual stars. Yet even if Herschel had no way of knowing what he was seeing, his observations laid a foundation for galactic studies.

By the 1920s, bigger telescopes and better techniques enabled Edwin Hubble to discern the real nature of galaxies. By the 1930s, his famous "tuning fork" classification scheme divided most galaxies into ellipticals and two types of spirals. Other galaxy-sorting systems followed, as astronomers studied galaxies in greater numbers and detail than Hubble ever could. But Hubble's system, as updated by Allan Sandage in the 1960s, retains a clarity that has kept it in use for generations.

Celestial pinwheels

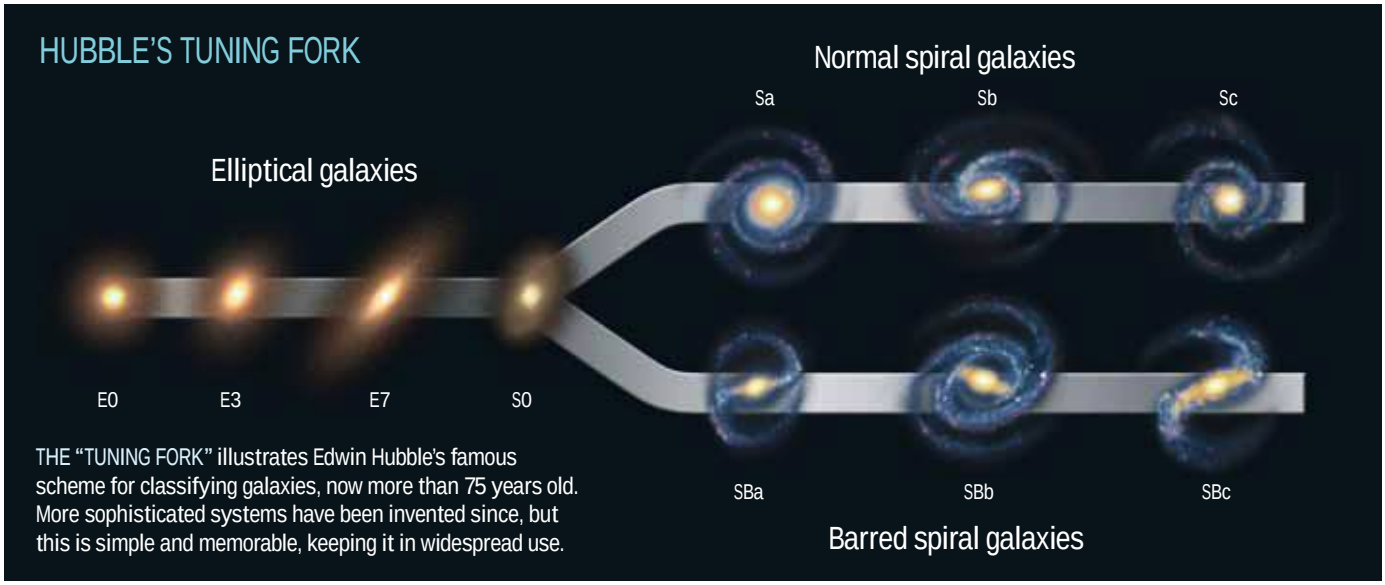
No other galaxy type shows the incredible range of form, structure, and dynamic history as do the spirals. And in the eyes of many, no other type is as beautiful, either.

Much like human fingerprints, no two spirals are exactly alike. Yet they show patterns in the spacing and strength of the spiral arms, the size of their cores, and the presence or lack of a bar and ring structures.

CLIFF WRIGHT

TIDAL FORCES from the smaller NGC 5195 are pulling out one arm of the giant spiral galaxy M51 in Canes Venatici. On a dark night, see if you can trace the arm connecting the two.

Spiral arms are the most spectacular and characteristic features of these galaxies, which appear in several types: grand design, multi-arm, and flocculent. Grand-design spirals have two well-defined, massive arms and are strongly bisymmetrical. Only about 10 percent of spirals fit this type. Classic examples include M51, M81, and the barred spiral NGC 1365. Astronomers think interactions of a spiral galaxy with a nearby galaxy trigger the formation of this type.



THE "TUNING FORK" illustrates Edwin Hubble's famous scheme for classifying galaxies, now more than 75 years old. More sophisticated systems have been invented since, but this is simple and memorable, keeping it in widespread use.

ASTRONOMY: KELLIE JAEGER

GIANT SPIRAL GALAXY M101 in Ursa Major shows arms that look like they have been disturbed. In the eyepiece, dimly glowing knots appear where the arms make angular bends.

TONY AND DAPHNE HALLAS

More numerous are multi-arm spirals, which include such bright galaxies as M83, M101, and M74. When you look at these with a medium or large telescope, it's the massive arms that identify them.

On the other hand, many short fragments form the arms of flocculent spirals. The Sunflower Galaxy (M63) and M94 are relatively bright examples of this class.

Not all spiral galaxies fall into nicely defined categories. Irregular one-arm spirals tend to occur in close pairs dominated by only one spiral arm. The Milky Way's neighbor, the Large Magellanic Cloud, has a strong bar and a single fragmented arm. Much farther out, the irregular spiral NGC 4618 has only one massive arm interacting with nearby NGC 4625.

Nearly all spirals rotate with trailing arms; however, every rule has an exception. The southern galaxy NGC 4622 actually rotates with the tips of the arms pointing in the direction of rotation. You can call this a leading-arm spiral — the galaxy literally rotates backward!

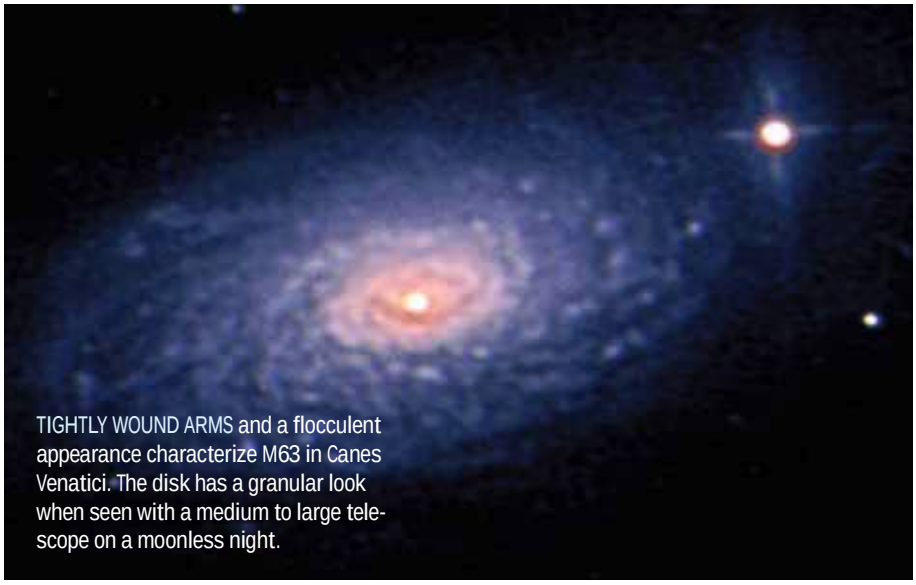
Another galaxy, NGC 4314, is an even weirder system. Overall, it appears as a typical barred spiral, except it shows another miniature, distinctly non-barred spiral structure in the core. This is a dual spiral galaxy, combining two apparently separate spiral systems.

Giants and dwarfs

Much like the stars that compose them, galaxies cover a big range of size, mass, and luminosity. Galactic diameters can range from less than 1,000 light-years to nearly a million. (For comparison, the Milky Way has a diameter of about 100,000 light-years.) The biggest giant galaxies have more than a million times the mass and brightness of the dimmest dwarfs.

Giant elliptical galaxies often dwell in the central regions of galaxy clusters and include some of the most massive of all galaxies. In the Virgo cluster, NGC 1399, M87, and M86 are superb examples of giant ellipticals.

Even more massive are the cD galaxies, similar to the giant ellipticals except for their huge outer halos. The term cD comes from an old galaxy classification system but could, in fact, stand for "cluster domi-



TIGHTLY WOUND ARMS and a flocculent appearance characterize M63 in Canes Venatici. The disk has a granular look when seen with a medium to large telescope on a moonless night.

JOHN CHUMACK

MARY JO RUSHING AND JIM LAWLER/ADAM BLOCK/NOAO/AURA/NSF

THE ANTENNAE GALAXIES in Corvus have become greatly distorted by their merger, which is stirring up the gas in each, producing a lot of star formation. Backyard telescopes reveal a tangled curl of light that just hints at the violence going on.

nating." NGCs 4874 and 4889 are two massive cD galaxies lying in the heart of the Coma galaxy cluster, some 400 million light-years away. Both are about 12th magnitude and have fairly high surface brightness, making them easily visible in 8-inch scopes. Larger instruments show a swarm of smaller galaxies around these two.

Even larger is NGC 6166, a supergiant cD galaxy that consumed a number of its smaller brethren. This 13th-magnitude object has in its core several nuclei, the remnants of smaller galaxies it shredded and consumed.

Like ellipticals, spiral galaxies also can reach gigantic dimensions. The beautiful M101 is a massive Sc galaxy more than twice the size of our Milky Way. But even M101 is dwarfed by UGC 2885, a 13th-magnitude Sc spiral located southwest of the California Nebula in Perseus. UGC 2885 spans an astounding 800,000 light-years and weighs in at over 2 trillion solar masses. It's the largest spiral galaxy known.

But not all galaxies classified as giants are large; some can be surprisingly small. The elliptical galaxy M32 might be called the "littlest giant," as it resembles its bigger brethren in star content and shape — except it's a fraction of their size. It may be the remnant of a larger system that once wandered too close to the Andromeda Galaxy.

By far the most common galaxies are dwarfs. Most members of our Local Group, for example, are tiny dwarf spheroidal galaxies. A few larger spheroidals, like M110 and NGCs 147 and 185, are fairly easy to see with even a small telescope. Most dwarf spheroidals are much smaller, however, and some are not much more luminous than a big globular cluster.

The largest and brightest members of the dwarf class — the Fornax and Sculptor galaxies — were discovered in 1938 by Harlow Shapley. The globular clusters belonging to the Fornax dwarf are easier to observe than the galaxy itself, and the brightest of them (NGC 1049) was discovered more than a century earlier. To observe these objects by eye requires very dark and transparent skies, a medium telescope, and a very wide field of view.

Dynamic duos

Many galaxies appear in pairs, yet not all pairings are real; some are just chance alignments in the sky. Often called overlapping or superimposed galaxies, many pairs have been targeted by the Hubble Space Telescope (HST). The Siamese Twins (NGC 4567/8) in Virgo are the most famous: a pair of 11th-magnitude spirals looking like a pretty, nebulous butterfly in the telescope. Other beautiful telescopic pairs include M60 and NGC 4647, NGC 2207 and IC 2163, and NGC 3314, where a smaller spiral galaxy stands directly in front of a larger spiral.

True double galaxies are fascinating to observe and include classes such as dumbbell galaxies and interacting pairs. Not to be confused with the Dumbbell Nebula, dumbbell galaxies got their nickname from their apparent shape — they are giant, co-rotating ellipticals lying in the center of galaxy clusters. Examples include

EXTREME ACTIVITY'S poster child, enigmatic galaxy M82 in Virgo is undergoing a burst of star-making that gives it a distorted appearance. In a backyard telescope, you'll see a bright central region with hints of outlying haze.

ADAM BLOCK/NOAO/AURA/NSF

Richard Jakiel *is an active deep-sky observer in the Atlanta area.*

GALACTIC SATELLITE M32 orbits the Andromeda Galaxy (M31) as the Magellanic Clouds do the Milky Way. Smooth and featureless in appearance, this dwarf elliptical resembles an elongated globular cluster.

WOLFGANG PROMPER

FRANCOIS AND SHELLEY PELLETIER/ADAM BLOCK/NOAO/AURA/NSF

AN ACTIVE NUCLEUS IN M77 tells astronomers this spiral galaxy in Cetus has a supermassive black hole hidden deep in its center. A telescopic view shows the bright nucleus surrounded by a wispy halo, with a bright star nearby.

NGC 545 and NGC 547 in Cetus, and NGC 4782 and NGC 4783 in Corvus.

Interacting galaxies result when two galaxies pass close enough to collide or merge. The famous Whirlpool Galaxy (M51) is the result of two galaxies passing close to each other. This pair is the archetype of a class of interacting galaxies that includes NGC 7752/3 — a nearly perfect twin of M51 — and NGC 1531/2, which resembles an edge-on version of M51.

Close passages or collisions of galaxies can pull out huge plumes and tails, raised by gravitational tides. Famous examples of this kind of extreme interaction include the Antennae (NGCs 4038 and 4039) and the Mice (NGC 4676). The weird shape of the Antennae can be seen in a medium scope, although detecting the wispy tidal tails requires at least an 18- or 20-inch under very dark skies.

Ring galaxies are the aftermath of a rare direct collision of two galaxies. They appear in two broad categories — the collisional (or equatorial) ring and the polar ring. The Cartwheel is a collisional ring galaxy, but it is quite difficult to observe. Much easier is NGC 985, whose faint ring is visible with a 16-inch or larger scope.

A polar ring galaxy is typically an SO galaxy with an equatorial ring aligned perpendicular to the main axis. The polar ring of the Helical Galaxy (NGC 2685) is too difficult to observe visually, but even a small telescope shows the galaxy's bright spindle shape.

ONLINE EXTRA For images of more galaxies, go to www.astronomy.com/toc

Starbursts and active galaxies

Starburst galaxies often result from recent or ongoing galaxy interaction. Large areas of these galaxies, studded with hot, blue giant stars and glowing HII regions, busily churn out new stars. The nearest example is IC 10, a small member of the Local Group visible in Cassiopeia.

The strange shapeless irregular M82 is undergoing a nuclear starburst and is one of the most richly detailed galaxies visible with a backyard telescope. Another starburst galaxy with an unusual shape is NGC 2537, known as the Bearpaw Galaxy.

Much larger in scale are ultraluminous infrared galaxies, or ULIRGs. These are powerhouses in the infrared and are undergoing massive bursts of star formation. Many are in the process of merging. One such monster is NGC 6240, a supergiant galaxy cannibalizing another galaxy.

Some of the most intrinsically luminous objects in the heavens are galaxies with brilliant nuclear regions. Astronomers term these galaxies AGNs, which stands for active galactic nucleus. In these galaxies, activity comes from matter flowing into a supermassive black hole at the galaxy's center.

AGNs span a range in energy output, with the lowest ranked being Seyfert galaxies. This class typically has a brilliant, starlike nucleus, and its members usually are spirals. Good examples include M77, NGC 4151, and the previously mentioned NGC 985.

Further up the power scale are the giant radio galaxies. NGC 5128 (Centaurus A) is a massive radio galaxy only 7.5 million light-years distant. It is consuming another spiral galaxy and has cannibalized smaller systems in the past. It makes a fascinating object in the telescope, and the massive dust lane across its middle is visible even in large binoculars. Another famous radio galaxy is M87. Its optical jet requires a large telescope and high magnification to see, but it's not overly difficult to capture using a CCD camera.

The last major class of active galaxy includes BL Lacertae objects (blazars) and quasars. These are superluminous objects whose total output can exceed that of a normal giant galaxy by hundreds of times.

Studies using HST and other large instruments revealed these galaxies have extremely energetic nuclei. Quasars often vary in brightness over weeks or even a day, and many brighter ones can be followed using backyard scopes.

The brightest (and one of the closest) quasars in the sky is 3C 273, a 13th-magnitude object in Virgo. At a distance of about 2 billion light-years, it's the most-distant object a small telescope can show you. Telescopically, it looks like just a star, but owners of 12-inch or larger instruments equipped with CCD cameras might have success imaging its optical jet.

Viewing most galaxies with an amateur telescope sometimes is dismissed as messing around with faint fuzzies. But every telescope embodies a spaceship of the imagination. With good observing conditions, a star atlas, and some patience, you can take yourself millions of light-years from home and explore the building blocks of the universe.

ASK ASTRO

Jupiter's Red Spot, gravitational redshift, color blindness and filters

JUPITER'S RED SPOT

Why doesn't Jupiter's Great Red Spot have an eye, like hurricanes on Earth? — FRANK HANOU, INDIANAPOLIS

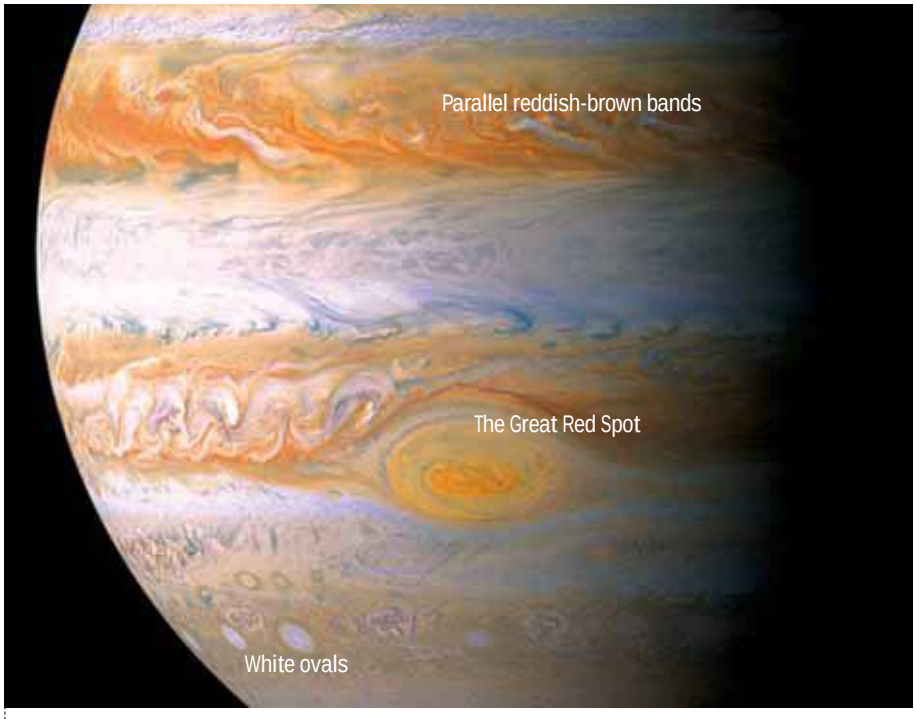
Jupiter's Great Red Spot is not analogous to a terrestrial hurricane. In fact, in many ways, it's the opposite phenomenon.

Earth's hurricanes are cyclonic, rotating counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere, thanks to Earth's rotation. Under the right conditions, a broad area of thunderstorms over a warm ocean surface becomes organized and forms a tropical storm. As this storm strengthens into a hurricane, it develops an "eye" of calm, stable, descending air at the storm's center, where the pressure is lowest. Hurricanes dissipate when they move over land or into cooler waters, depriving them of their energy source.

Jupiter's Great Red Spot has been observed for centuries, with its appearance changing slightly. Like other oval spots in the atmospheres of gas-giant planets, the Red Spot is an anticyclone — a dome of high-pressure gas rising above the surrounding atmosphere, spinning counterclockwise in Jupiter's Southern Hemisphere. Fast-moving jet streams seem to create a stable shear that contributes to the long life of jovian anticyclones. Instead of having a central eye, the spots are encircled by a ring of calm, stable, descending gas.

In 2000, cameras aboard the Cassini spacecraft monitored Jupiter's atmosphere for more than 2 months. In that time, nine small spots drifted westward along the planet's South Equatorial Belt to be absorbed by the Great Red Spot. A turbulent region west of the Great Red Spot seems to be a source for what appear to be thunderstorm-like features. Farther west, the South Equatorial Belt spawns anticyclones. Planetary scientists suspect these features play a role in maintaining the Great Red Spot.

— RICHARD CROWE, UNIVERSITY OF HAWAII, HILO



NASA/JPL/SSI

CASSINI IMAGED JUPITER when it passed the giant planet in 2000. Parallel reddish-brown bands, white ovals, and the Great Red Spot persist throughout many years despite the atmosphere's intense turbulence. The Red Spot is big enough to hold two Earths side-by-side. Brown and orange colors likely come from sulfur- or phosphorus-bearing trace chemicals lofted from deep within the atmosphere or created in chemical reactions driven by sunlight.

GRAVITATIONAL REDSHIFT

How did physicists measure the gravitational redshift of light?

— JERRY T. SEARCY, SCOTTSDALE, ARIZONA

It's one thing for a theorist like Einstein to make a prediction, but quite another for someone else to do an experiment that tests it. Nowhere is this more true than in the case of gravitational redshift.

If you shoot a light beam straight up from Earth's surface to the top of a 100-foot (30.5 meter) tower, relativity predicts the light frequencies measured at the top and bottom of the tower will differ. Specifically, light at the top of the tower will be shifted into slightly longer, redder wavelengths.

The trouble is, this difference appears only in the fifteenth decimal place. So, if you can't determine the light's actual frequency to something close to this accuracy, you won't be able to tell the wavelength difference between light at either end of the tower — and you won't be able to test this Einstein prediction.

Atoms emit light when electrons jump from one orbit to another. When you look at the light given off by a collection of atoms, some emitting atoms are moving toward you and some away. This movement results in slight changes in the frequencies of light observed from different atoms. This is the Doppler effect. In addition, when atoms emit light, they recoil just as a gun recoils when it "emits" a bullet. This, too, changes the frequency of light an observer sees. These effects — and many others — smear the frequencies of light so we detect a range of frequencies spread out in the familiar bell curve. If the bell curve's width is too big, this smearing hides the small gravitational redshift associated with relativity.

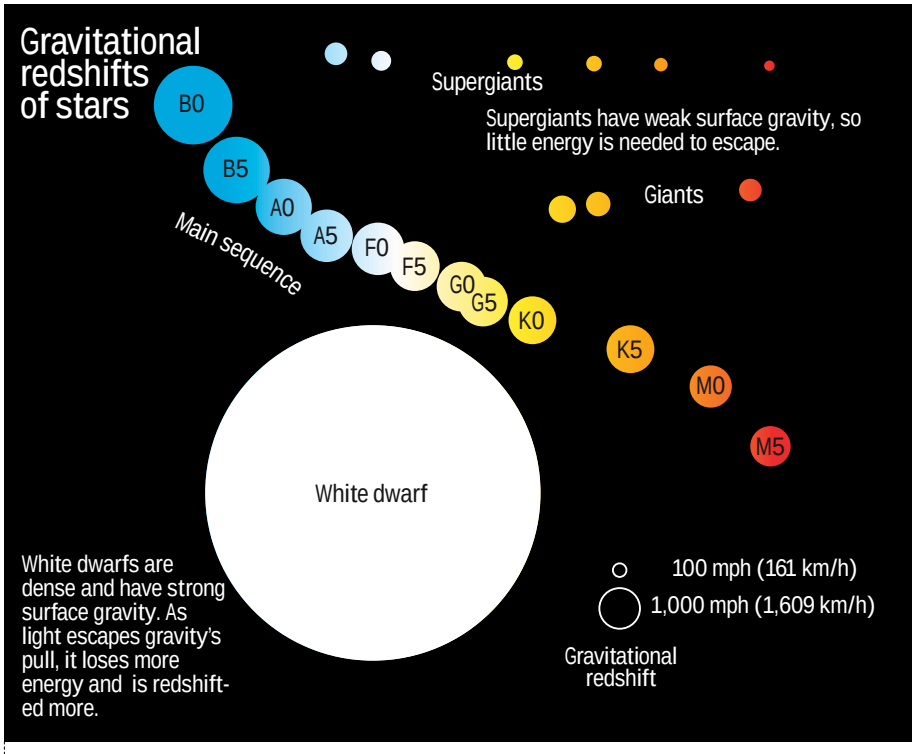
Today, we use lasers to produce light at precise frequencies. But lasers weren't available in 1959, so in order to test this aspect of relativity, physicists had to find some other way to reduce the width of the bell curve.

Two American physicists, R. V. Pound and G. A. Rebka, realized they could apply a newly discovered phenomenon to the task. Certain atoms in solids emit precise frequencies due to the Mössbauer Effect. Atoms in solids are locked in a crystal lattice, so when an atom emits light, it shares its recoil among all the atoms in the system. This greatly reduces the emitted light's frequency spread and reduces the width of the bell curve.

In 1960, when Pound and Rebka carried out the tower experiment, they found they could produce bell curves only 100 times wider than the expected difference in frequency between the top and bottom of the tower. With some experimental and data-analysis tricks, this allowed them to see the gravitational redshift for the first time.

This illustrates an important point. Sometimes answers to the deepest questions (in this case, the nature of space-time) depend on the grubbiest details of experimental technique (like measuring the frequency of a light beam).

— JAMES TREFIL, GEORGE MASON UNIVERSITY, FAIRFAX, VIRGINIA



ASTRONOMY: TOM FORD AFTER DRAVINS ET AL., LUND OBSERVATORY

THE GRAVITATIONAL REDSHIFT expected in light from different stars ranges over a factor of 1,000. The symbol size indicates the apparent velocity change astronomers could measure in each star type due to this effect. Small, dense white dwarfs have high surface gravity, so light leaving them loses more energy and has a greater gravitational redshift. Despite their mass, supergiant stars have comparatively lower densities, and so lower gravitational redshifts.

COLOR BLINDNESS AND FILTERS

I am red-green color-blind. Will color filters enhance planetary or deep-sky object detail for me?

— MARIO MOLINA, PHOENIX

Yes. A color filter's purpose is to exaggerate differences in brightness, to increase the contrast between light and dark portions of the object under view.

Consider, for example, using a blue filter to view Jupiter. What you see is a grayscale image of the planet, not one that is tinted blue. This is why many amateur astronomers find viewing planets through color filters unappealing.

For Jupiter, a blue filter brings out detail in Jupiter's bright zones and sharpens the brighter cloud features. Yellow filters darken bluish features — such as the festoons that appear from time to time within Jupiter's equatorial region. Red filters brighten and enhance white spots and ovals in the planet's south temperate region.

Your red-green color blindness should not affect what you see, except where you perceive a specific wavelength of light (color) better or worse than another observer. Experiment with different color filters, and see which ones work best for you.

Color filters are not recommended for observing deep-sky objects. However, nebula filters, which block out all but specific light wavelengths, can help you observe bright nebulae. They come in different types: LPR (light-pollution reduction), UHC (ultra-high contrast), and OIII. An OIII filter transmits only light from doubly ionized oxygen and works best on planetary nebulae. Your view through these filters will also be uncolored. — MICHAEL E. BAKICH, ASSOCIATE EDITOR

On July 4, Deep Impact will blow a hole in Comet Tempel 1. Don't miss it. /// BY ALISTER LING

Fireworks on the Fourth

This summer could provide the most exciting comet observations ever. Scientists are slamming a projectile into Comet 9P/Tempel 1, and — just maybe — the effects will be visible through a backyard telescope.

To best appreciate the impact, get to know Tempel 1 before it changes forever. A comet is described best as a "dirty snowball," a concept first proposed by American astronomer Fred Whipple more than 50 years ago. It is a chunk of primordial matter left over from the solar system's creation. A typical comet is the size of a small mountain, just a couple of miles across.

A comet's surface is not much more reflective than a blacktop highway. Crater walls and fissures expose ice to sunlight. Solar energy evaporates the ice directly (liquid water cannot exist in these conditions), releasing any dust trapped within the comet. Ejected dust enshrouds the nucleus in a sunlit cloud called the "inner coma." It blocks our view of surface events.

Beyond Jupiter, sunlight produces little dust. As a comet approaches the Sun, dust production increases. More dust and sunlight quickly increase the comet's brightness.

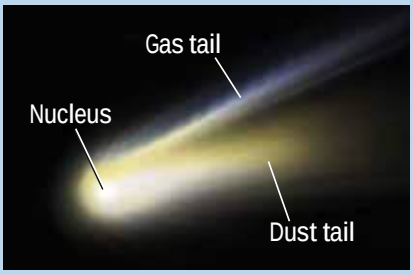
When Ernst Tempel first saw Tempel 1 in 1873, he was searching deliberately. In 1866, Tempel had codiscovered Comet 55P/Tempel-Tuttle, the parent comet of the Leonid meteor shower. Astronomers computed the 1873 comet's orbit and recognized it was the ninth comet known to return periodically, leading to its modern-day designation of 9P/Tempel 1.

Jupiter perturbs Tempel 1's 6-year orbit significantly. In fact, the comet was lost for almost a century due to a close passage to Jupiter in 1881 that changed its orbit. Astronomers recovered Tempel 1 in 1972.

/// THE TALE OF THE TAIL

Comets typically produce two types of tails: gas and dust. The gas (ion) tail forms as chemical elements break apart because of the sunlight and glow as their electrons recombine with protons. By studying the spectrum, scientists can determine the comet's makeup.

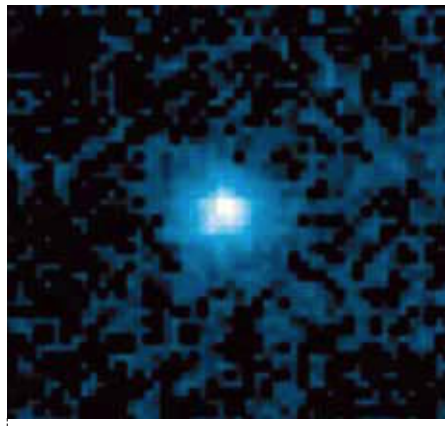
Typically, a comet's gas tail is a faint slate blue, but it can be green sometimes. Pressure from the solar wind makes it straight and carries it away from the Sun.



ASTRONOMY: ROEN KELLY

Dust is heavier than gas, so cometary dust particles tend to orbit the Sun with the comet. The bigger the specks and clumps of dust, the less effect the solar wind has, producing a gradually curved tail. Just as dust in Earth's atmosphere scatters sunlight, the comet's dust tail tends to be pale-yellow or white.

Take a close look on a few evenings either side of July 9. Earth will look right along the plane of the comet's orbit then, so we may see an "anti-tail" appearing to point toward the Sun. Imagine a hand fan, spread it out, and look at it edge-wise, with the hinge closest to your eyes. You'll see material on both sides of the hinge, which, in this case, represents the comet's nucleus. – *A.L.*



KECK OBSERVATORY

COMET TEMPEL 1 was visible but not bright when imaged August 21, 2000. This infrared image shows how the comet is radiating heat.

This is no Hale-Bopp

You'll be able to find and follow Tempel 1 with a 4-inch telescope from a dark site. However, it won't be bright like Comet Hale-Bopp was a decade ago. Know when and where to look — it will be worth it. And, hopefully, you'll see the comet change after it's been smacked.

From late May through early June, Tempel 1 glows between 10th and 11th magnitude, similar to the toughest galaxies on the Messier list. Fortunately, it will be relatively easy to locate near Delta (δ) Virginis, to the upper left of brilliant Jupiter as viewed from the Northern Hemisphere. Also, during this time, the Moon is out of the evening sky. Wait until twilight ends to begin your search. If you're trying to see Tempel 1 from suburbia, a 10-inch scope probably is the required minimum.

On June 4/5, Tempel 1 passes less than 1 apparent Moon-width from NGC 4845. Compare the two objects. The elongated spiral galaxy has a partially obscured

Alister Ling *is a meteorologist for Environment Canada and a long-time comet watcher.*

/// FLY-BY SHOOTING

The Deep Impact spacecraft, launched January 12, 2005, will study the pristine interior of comet 9P/Tempel 1. Literally executing a "fly-by" shooting, Deep Impact will release a large copper "bullet" 24 hours before striking ground zero.

The bullet's onboard guidance system homes in on the comet. To minimize the chance of a miss, the main vehicle keeps a close watch, swinging past at a tight but safe distance of 300 miles (500 km). Because of the speed of the interception, there's only one chance to get everything right. The result will be a crater 80 feet deep and more than 300 feet wide (25 by 100 meters).

The science instruments on the primary vehicle will capture images during the encounter. Also, spectroscopy will analyze the chemical composition of the spray. Unfortunately, the data transmission rate isn't high enough to run live video. But that won't stop scientists from learning how a comet's interior is different from its surface. NASA plans to broadcast the event on television and on the Internet, so we'll see images arrive in near-real time.

Will this fastball pitch alter the comet's course? No. As impressive as it sounds, it's like firing a peashooter at a moving snowman. The long-term gas and dust production of the comet caused by the Sun's radiation has a far greater (but still small) effect on the orbit.

Deep Impact is one of NASA's Discovery missions, a low-cost but focused approach to solar-system science. The probe was launched on a simple arc to reach the comet in the shortest time at the highest speed. Other missions to land on a comet and return a sample need to match a comet's speed and trajectory more accurately. – *A.L.*

NASA

THE "IMPACTOR" SPACECRAFT launched from Deep Impact weighs 820 pounds (370 kilograms). It will strike Comet Tempel 1 at 23,000 mph (36,700 km/h).

Bang!

Impact date: July 4, around 2 A.M. EDT

Mass of impactor: 820 pounds (370 kilograms)

Speed of impact: 23,000 mph (36,700 km/h)

Energy released: Equivalent to 4.8 tons of TNT

NASA

DEEP IMPACT was launched toward Comet Tempel 1 January 12 aboard a Delta II rocket.

center; the rounder comet has a halo that brightens quickly to a sharp central point.

Look carefully at the comet's periphery. One flank should be sharper. This edge is the "bow shock," where the solar wind pushes the dust outward.

From June 8–23, the evening sky is awash with moonlight. This natural form of light pollution hides the outer coma and makes low-contrast features difficult to make out. These 2 weeks are prime time for CCD imagers because the extra light can be electronically subtracted from the image.

Best viewing

Dark skies return after June 23, when the Moon rises in late evening and, finally, after midnight. Tempel 1 is now sliding just north of bright Spica (Alpha [α] Virginis) and has brightened to about magnitude 9.5.

Start with low power to locate the comet and to familiarize yourself with its overall character. Zoom in for a more detailed view of the central area before starting to look at the tails. Straight features are evidence of either jet activity or that you're looking through a thicker part of the tail.

Practice your observing by increasing the magnification. Although the field of view darkens, your eye better detects faint structure when that structure occupies more of the field. Be patient — you can't train to expert level in a night. The more you observe, the more detail you'll see.

Slowly move your eye around, and try to pick out high-contrast zones. Use averted vision — look to the side of the comet but note what's in the middle.

Ker-splat!

In a solar system first, humans will slam a large copper weight into Tempel 1 July 4. Scientists hope to excavate a crater and see if new jet activity develops from the freshly exposed material.

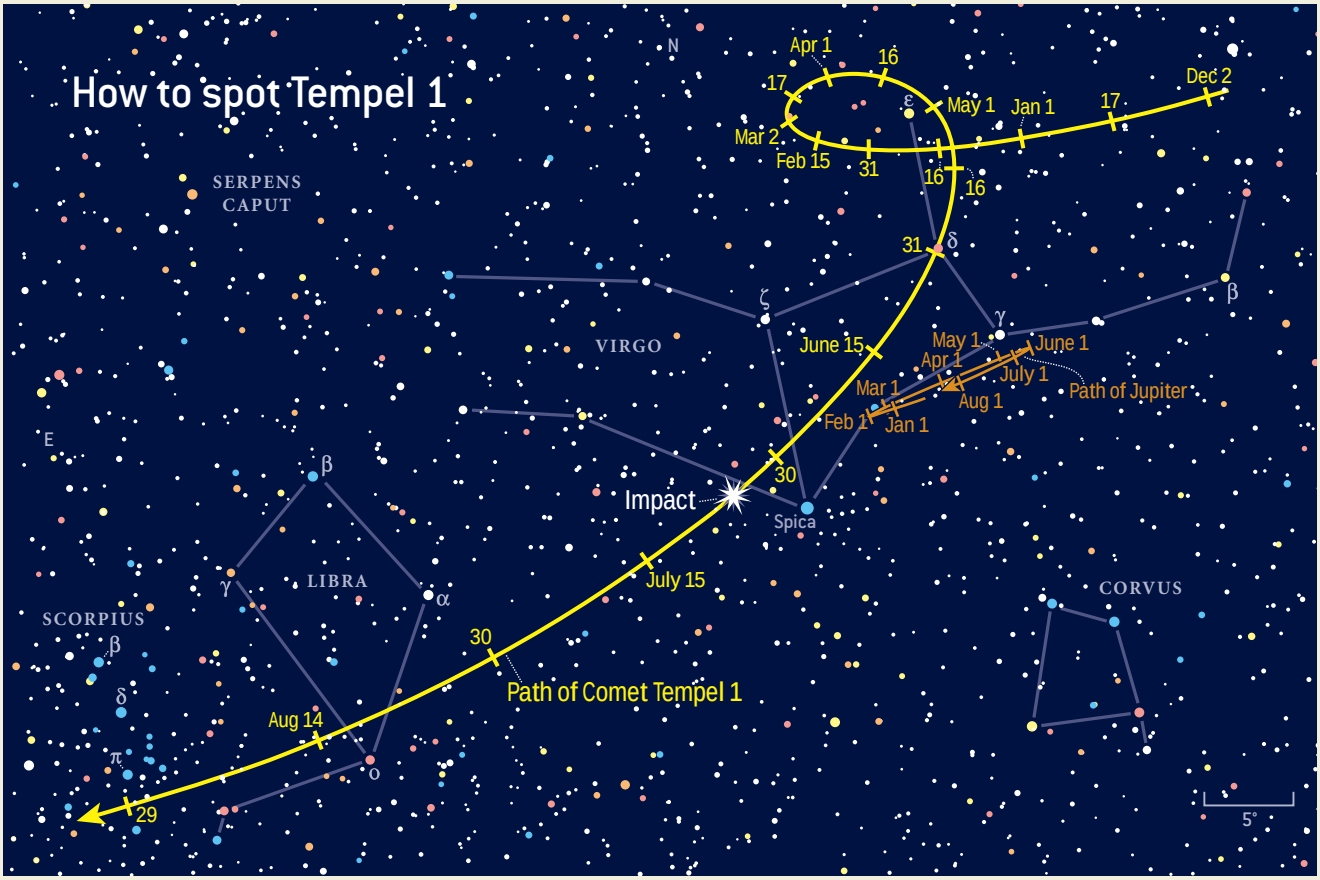
/// COMET WATCH

Learn how amateurs worldwide are helping the mission with round-the-clock coverage of Tempel 1's behavior before, during, and after impact. Information about the Deep Impact Mission's Small Telescope Science Program and a registration form can be found at *deepimpact.umd.edu/stsp*. Observers with telescopes as small as 8 inches are participating. – *A.L.*

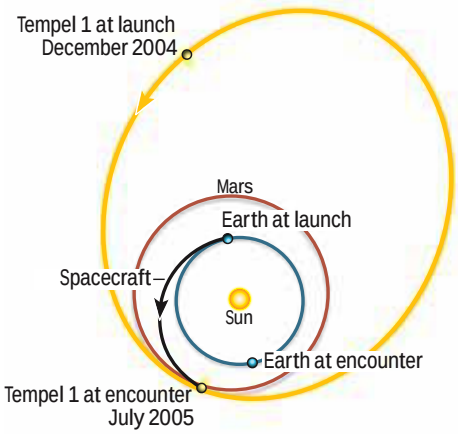
If all goes as planned, impact will occur at 2 A.M. EDT. East of the Mississippi River, the comet will have already set. West-coast observers may see the comet brighten during the following minutes and hours. Check the Deep Impact web site, *deepimpact.jpl.nasa.gov*, for an up-to-the-minute schedule.

No fireworks in the usual sense will occur because the projectile isn't a bomb. However, the impact speed of 23,000 mph

Use this chart to zero in on the area. Remember, Newtonian telescopes rotate the image 180°. Refractors and Schmidt-Cassegrain telescopes with star diagonals leave the image upright but flip it left to right. Even from the countryside, the background sky can be bright enough at low power to hide the comet's faint, fuzzy glow. Nudge the power up to about 100x. Try using a dark cloth or towel to cover your head and eyepiece. By eliminating as much stray light as possible, you can see faint objects and details more easily. Also, try not to fog the eyepiece with your breath.



COMET TEMPEL 1 will be in Virgo the Maiden before and after its encounter with Deep Impact. Note the positions of Jupiter and Spica, two bright objects that will help you locate the field of Tempel 1. This chart presents a normal view, with north up and east to the left.



KEY POSITIONS of Tempel 1, Deep Impact, and Earth, as well as the orbits of planets out to Jupiter, appear in this diagram. Deep Impact's travel time to Tempel 1 is approximately 6 months. ASTRONOMY: ROEN KELLY

(36,700 km/h) packs quite a punch. There should be lots of stuff blown off the comet.

Mission leaders hope the effects will be visible through 8-inch scopes. Most likely, observers simply will see a brighter comet from one night to the next. Scientists suspect the spray from the collision itself will be too small to see.

Maybe Tempel 1 will brighten and fade dramatically as the new zone rotates in and out of the Sun's rays. Because astronomers are unsure of the comet's orientation and spin or the exact location of the impact, it's impossible to know what will be seen.

Moonlight returns to evening skies by the second week of July. Wait until moonset, and you can observe in darkness up to July 10. After that, it's a good idea to keep a close watch, just in case.

Winding down

By the end of July, Tempel 1 will be cruising slowly about halfway between Spica and Antares (Alpha [α] Scorpii). For much of the Northern Hemisphere, its position low in the sky will begin to affect observations. Take advantage of a late-summer star party to get a good look at it from a dark site with a large scope.

As Tempel 1 speeds away from the Sun, it will become less active. Keen observers can follow it through August as it slides beneath Scorpius. Astrophotographers will grab farewell shots as it poses with star cluster M6 on the evening of October 1.

After that, the comet will slowly limp off into the sunset, shot through the heart with a boulder-size copper bullet by the gunslingers at NASA.

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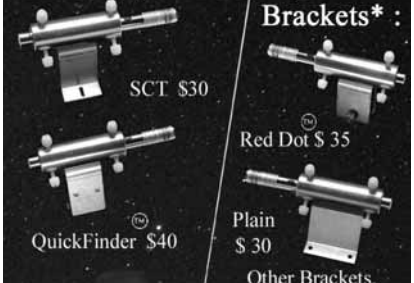

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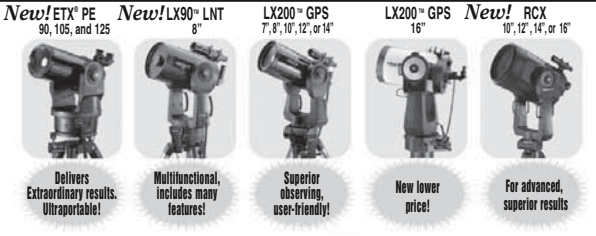

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17.0	Nagler	Type 4	$385.00	7.0	Nagler	Type 6	$280.00	10mm	Radian		$240.00
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A veteran astrophotographer captures the cosmos with Canon's Digital Rebel.

/// TEXT AND CELESTIAL IMAGES BY JACK NEWTON

Newton's universe

A revolution has begun in amateur

astronomy, ushered in by easy-to-use, high-resolution, and relatively inexpensive digital cameras. If you've ever thought about imaging celestial objects, there's never been a better time than now. « Astroimagers have used CCD cameras for 14 years. Until recently, chip size has been small compared with the 35mm film that dominated astrophotography for 45 years.

While early chips were suitable for imaging small celestial objects such as galaxies and planetary nebulae through an 8-inch telescope, they weren't large enough to capture most popular celestial objects. The small chips also made it a challenge to find and center objects. CCD cameras with ½-inch-wide chips were considered large and cost around $7,000.

A color CCD image emerged only after taking separate red, green, blue, and (in many cases) luminosity images. The colors then were combined to create the final "LRGB" image.

A new technology emerges

In the past few years, we've seen numerous "point-and-shoot" digital cameras. While a chip's imaging area is small compared to 35mm film, the quality and resolution are excellent. The big disadvantage is that you can't use these cameras for prime-focus imaging (where the telescope becomes the camera's lens) because of their fixed lenses.

Thus, many potential astroimagers are sitting by the sidelines. Well, if you've hesitated to make the jump to astroimaging, the wait is over! Single-lens reflex digital cameras are here, and one of the best lines I've used is Canon's EOS Digital Rebel series.

The Digital Rebel has a 6.3 megapixel CMOS (complementary metal oxide semiconductor) chip measuring 0.9 by 0.6 inch (22.7 by 15.1 millimeters). Its pixels are arranged in 3,072 rows by 2,048 columns; multiply the two numbers to get 6.3 megapixels. Each pixel measures 7.3 microns across. The Digital Rebel's CMOS sensor is low-noise and draws little power. The cameras in the Rebel line are priced between $799 and $1,000.

Want a quick picture of the sky? Attach a Digital Rebel to a sturdy camera tripod and point the camera skyward. In manual mode, the Digital Rebel can take exposures of up to 30 seconds at ISO ("film-speed") settings as high as 800.

/// REBEL MODIFICATION

The Digital Rebel is most sensitive to green light and least sensitive to red. The color balance is approximately 2.25 parts red, 1 part green, and 1.25 parts blue.

The Hutech Corporation (www.sciencecenter.net/hutech) offers versions of the Rebel 300D optimized for astrophotography. Hutech replaces the internal filter with one of several broader-band filters.

These filters extend the camera's red sensitivity, enhancing celestial images. Once modified, the auto focus still works; however, you must take a new white balance calibration exposure.

CANON'S DIGITAL REBEL is a versatile camera for astrophotographers. Here, the lens has been replaced by a T-adapter.

ASTRONOMY: JAMES FORBES

The Orion Nebula

The California Nebula

Lunar eclipse, October 27, 2004

The Pleiades

The Crab Nebula

The Witch Head Nebula

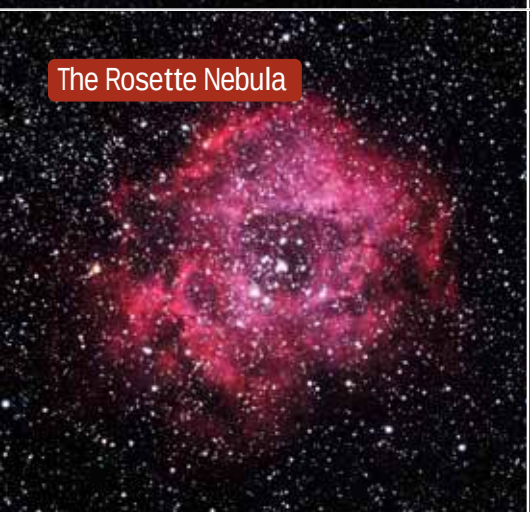
The Helix Nebula

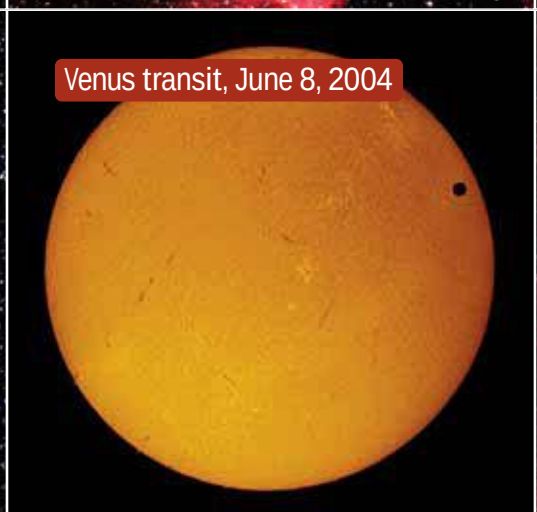
The Flame and Horsehead nebulae

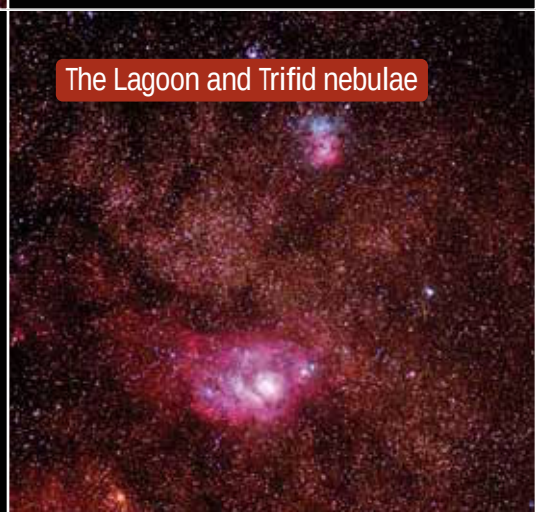
The Andromeda Galaxy

The North America Nebula

Zodiacal light


The Rosette Nebula


Venus transit, June 8, 2004


The Lagoon and Trifid nebulae

Aurorae, July 25, 2004, from Osoyoos, British Columbia

Images are stored on a CompactFlash memory card (a separate purchase) in JPEG or RAW formats. On longer exposures, a trace of noise (glow) on the image's right edge is caused by a variance in temperature from adjacent electronics. You can eliminate this by turning on the camera's noise-reduction feature.

For long exposures, use a T-adapter to connect the camera to a telescope. You'll need a cable release also. Canon sells manual and wireless cable releases.

The Digital Rebel's best feature is it can be controlled by a computer and operated like a CCD camera. You'll require a serial cable (additional purchase) that plugs into the camera's remote-control jack. You also will need to connect the included USB download cable.

Celestial portraits

I tested the camera piggybacked on a friend's 12-inch Meade LX200. The lens was a 14mm Tamron at f/2.8, and the Rebel was set on "bulb" exposure and ISO 800 sensitivity. I saved four 5-minute exposures. The images were stunning, and this was only a quick test.

Jack Newton *is a world-renowned film and digital astrophotographer and manager of Arizona Sky Village in Portal, Arizona.*

I chose the Andromeda Galaxy (M31) for my first "real" celestial image. I mounted a 4.4-inch William Optics Fluoro-Star FLT 110 telescope at f/6.5 onto my 16-inch Meade LX200.

Because M31 is a large object, I took nineteen 5-minute exposures of each half. I used *MaxIm DL* to subtract the dark frame, turn on the raw images' color matrix, and stack the images. I was able to knit the two halves of the image together in Adobe *Photoshop CS*.

I mounted a 4-inch Borg Series 80 telescope at f/4 on my LX200 and imaged M31, combining eight 5-minute exposures. Through this scope/camera combination, M31 looked great.

The Rebel permits focusing through the telescope. I can't tell you how refreshing it is to frame and focus the desired object or field using such a camera design. Its CMOS chip bleeds off excess light from bright stars to prevent overexposure (or "blooming"). This feature is helpful when imaging bright objects such as star clusters like the Pleiades (M45).

Are you ready to image?

Cameras like the user-friendly Canon Digital Rebel bring astroimaging to the masses. It's a lightweight camera with superb performance and low background noise. Now when I travel to remote, dark sites, I can take the Rebel and a small refractor and not need filter wheels, reams of cables, or a computer. On a memory card, the camera can store celestial images as well as the rest of the vacation photos, and that pleases the whole family.

Amazingly enough, the astronomy digital camera era is only a year old. But as far as astroimagers are concerned, things will only get better. *Viva la revolución*!

/// CCD-LIKE CONTROL

Computer control requires a plug-in for *MaxIm DL* for the camera. If you own a copy of *MaxIm DL*, the plug-in is available for $60 ($98 with the serial cable) at *www.bearcreekobservatory.com*. The plug-in allows use of the features of *MaxIm DL* — taking the exposures and processing the Rebel images using dark subtraction and flat fields, similar to the process with a CCD camera.

Another program for controlling the Digital Rebel and processing its images is *Images Plus*. It costs approximately $197, and a free demo version is available through *www.mlunsold.com*.

ONLINE EXTRA For more Jack Newton images, visit www.astronomy.com/toc

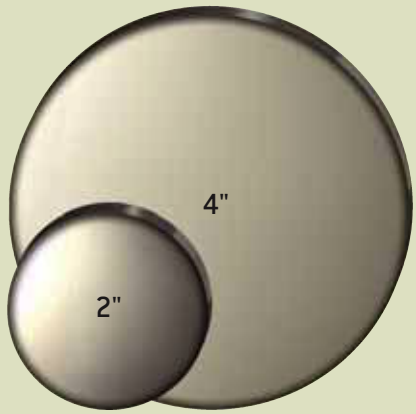
Fifteen things you need to know before buying a telescope. /// BY MICHAEL E. BAKICH

Telescopes 101

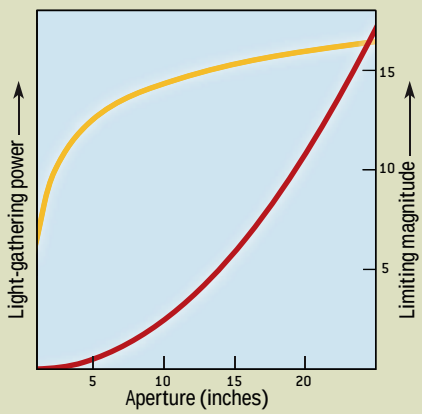
Buying a telescope is a big step,

especially if you're not sure what all those terms — f-ratio, magnification, go-to — mean. So, to eliminate confusion and make sure you understand what you're buying, here's what to check out before you write the check out.

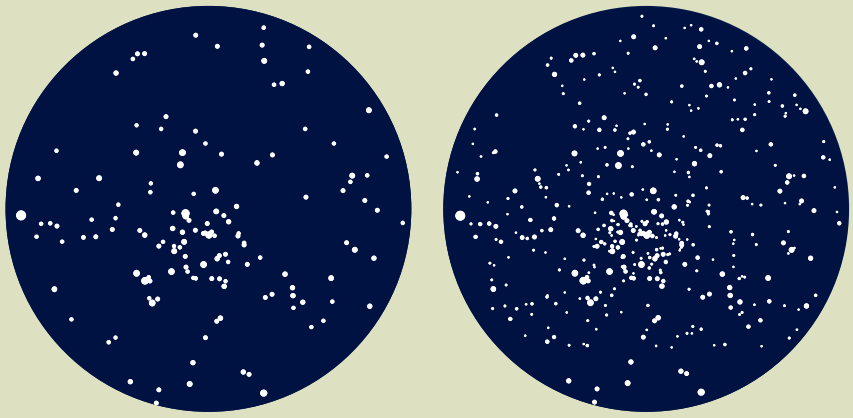
/// LIGHT-GATHERING POWER: WHY "BIGGER IS BETTER"



A 4-INCH DIAMETER MIRROR has 4 times the light gathering area of a 2-inch diameter mirror.



A LARGER SCOPE GATHERS more light, and therefore, you can observe fainter objects.



THE FAINTEST STAR you can see through your telescope — "limiting magnitude" — depends on the size of the objective. A star field is shown above through a 2-inch (left) and a 4-inch (right).

1 I know telescopes make things appear bigger, but what *exactly* do they do?

A telescope's main purpose is to collect light. This property of telescopes allows you to observe objects much fainter than you can see with your eyes alone. Galileo said it best when he declared his telescopes "revealed the invisible."

2 When I buy my first telescope, will it be complete, or will I have to buy additional items to make it work?

Most telescopes marketed to beginners are complete systems, ready for the sky as soon as you unpack them and perform whatever setup procedures the manufacturer recommends. Some high-end models are sold as "optical-tube assembly only" versions. This means what it says: All you're purchasing is the optics in the tube — no mount, tripod, or accessories.

Refractors usually need a star diagonal because of their design. A star diagonal bends the light from your target object 90°, so without one, you find yourself in some awkward positions when you're observing objects high in the sky. The star diagonal fits into the telescope's focuser, and the eyepiece fits into the star diagonal. Most manufacturers that provide complete refractor telescopes include a star diagonal.

3 I'm interested in observing, but I don't know which scope to buy. What should I do first?

Your first step should be to learn all you can about telescopes: what types are available (see "Telescope types" to upper right), what manufacturers sell them, and what words describe them. Page through the ads in this issue, and you'll see a range of what's available.

ALL ILLUSTRATIONS ASTRONOMY: ROEN KELLY

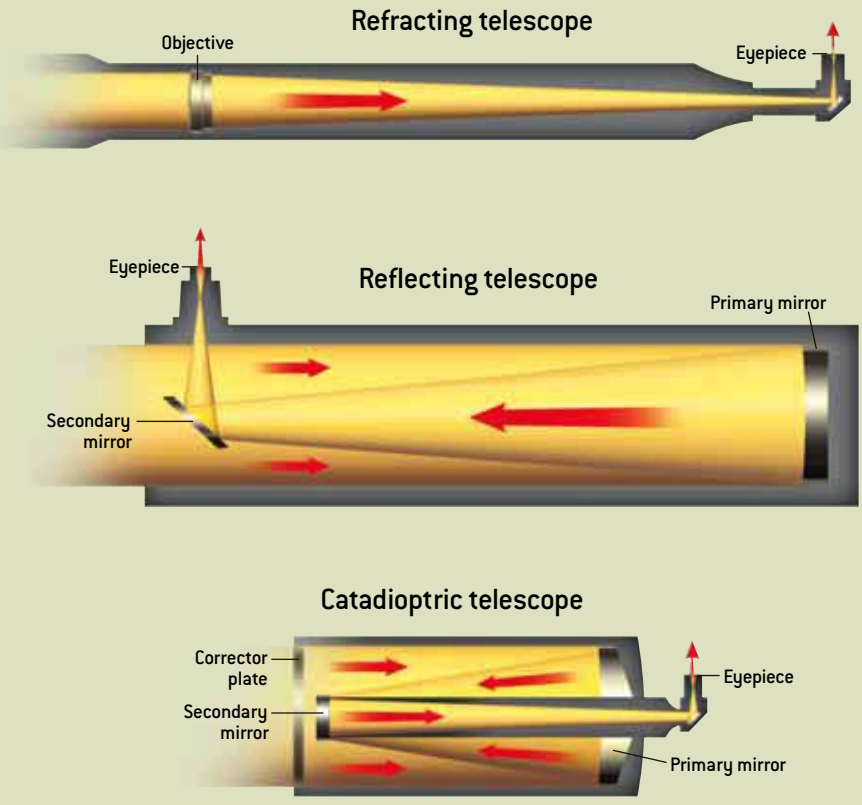
/// TELESCOPE TYPES

The three main types of telescopes use lenses, mirrors, or a combination of both.

REFRACTING TELESCOPES use lenses — combining at least two, and as many as four, pieces of glass — as their objective (the primary light-gathering device).

REFLECTING TELESCOPES use mirrors to gather and focus light. In a Newtonian reflector — the most common type — light reflects from the primary mirror (whose surface is ground into a parabola so light comes to a common focus). The light strikes a smaller, flat secondary mirror near the top of the tube. The light then is bent 90° and enters the eyepiece through a small hole in the tube.

CATADIOPTRIC, OR COMPOUND, TELESCOPES incorporate a primary mirror coupled with a corrector lens placed at the front of the tube. The primary mirror's curve is ground to a simple shape, usually a sphere. Ordinarily, a spherical mirror would introduce aberrations in the viewed image, but the corrector of a catadioptric scope "pre-bends" the light before it strikes the mirror. Two popular catadioptric telescopes are the Schmidt-Cassegrain and Maksutov-Cassegrain designs. — *M.E.B.*



For each telescope that interests you, visit that manufacturer's web site. When you're finished reading this story, refer back to recent issues of *Astronomy* and carefully read telescope reviews. You may not understand everything discussed in each review, but you'll get a taste of telescope terminology. By doing this, you'll learn what's important to observers when they use a telescope. You'll get a feel for optical and mechanical quality, ease of use (including portability), extra features, and — perhaps most importantly — which objects the telescope excels on.

4 Is it true that I should purchase binoculars before a telescope?

No. I used to give this advice to beginning amateur astronomers, but not any more. The view through binoculars — especially from a light-polluted site — often proves disappointing to beginners. However, high-quality binoculars are a valuable observing accessory. Large star clusters look great through binoculars, as do the Milky Way band and the Moon.

5 What are the sizes of "small," "medium," and "large" telescopes?

I can't speak for every reference to small, medium, or large telescopes — these terms are not standardized — but here at *Astronomy*, when we refer to a "small" scope, we specifically mean a telescope with an aperture (size of the lens or mirror) less than 4 inches. The type of scope doesn't matter, and neither does the quality. Many small telescopes manufactured today are high-quality instruments I am proud to use.

"Medium" telescopes have apertures from 4 to 10 inches. This category is the size most amateur astronomers use. One of the most popular scopes is an 8-inch Schmidt-Cassegrain.

Finally, any telescope with a lens or mirror larger than 10 inches is "large." More large telescopes are in use today than ever before. The introduction of Dobsonian mounts is largely responsible for this. Newtonian reflectors coupled to alt-az Dobsonian mounts (see "Telescope mounts" on next page) dramatically reduce the prices (and weights) of large telescopes from what they would be with a motor-driven, equatorial mount.

6 I've heard "bigger is better" is true when it comes to telescopes. What are the real advantages of big scopes?

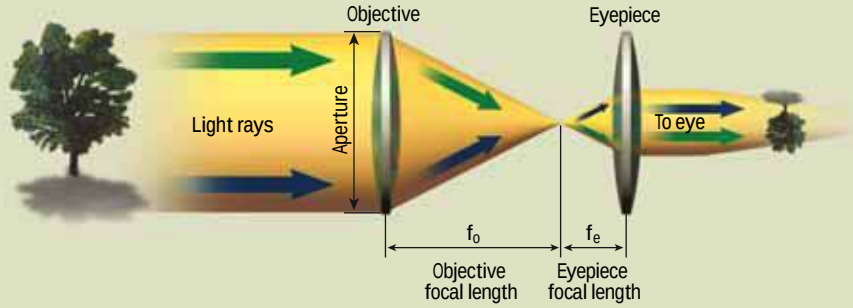
The larger the telescope's diameter, the more light it will collect. A 4-inch refractor, for example, is a great scope for planets, the Moon, and double stars. I know because I own one, and I wouldn't part with it for love or money. This size scope, however, is a bit small for deep-sky objects such as nebulae, star clusters, and galaxies.

An 8-inch telescope (it doesn't matter what type) will move you into a new dimension of viewing. The objects you see with an 8-inch scope will reveal more detail. Keep in mind, however, that if you stay interested in observing, you'll crave even larger scopes. This malady among amateur astronomers is known as "aperture fever." And, yes, I'm infected. I started many years ago with a 2.4-inch telescope of good quality. I now own a 4-inch

/// LET'S TALK OPTICS

The f/4, f/10, or f/15 represent a telescope's focal ratio (f-ratio). Focal ratio is determined by dividing the focal length (the distance from the objective to where the light comes to a focus) by the aperture. Here's an example: A 6-inch telescope has a focal length of 36 inches. To find the f-ratio, divide 36 by 6. This produces f/6. Often, the aperture is in inches, but the focal length is given in millimeters. If so, just multiply the inches by 25.4.

To find magnification, simply divide the telescope's focal length (f_o) by the eyepiece's focal length (f_e). For example, if your telescope has a focal length of 1,000mm and you choose a 25mm eyepiece, the magnification will be 40. Remember, magnification alone is not a good indicator of telescope quality. Magnification is determined by which eyepiece you use with any telescope. So, a low-quality scope can have a poorly made eyepiece, and the combination can give high power. But any images viewed through it will look distorted — although they will be magnified as claimed. — *M.E.B.*



THE IMAGE IS "UPSIDE-DOWN," although there is no up or down in space.

/// FINDER SCOPE SETUP

Align your finder scope during the day. Most observers take time before each observing session to check their finder scope's alignment. Here's how:

- ☐ Insert a low-power eyepiece in your telescope for initial alignment.
- ☐ Loosen your scope's motion-control locks to allow movement.
- ☐ Move your telescope until you center a distant object (the top of a transmission tower, tree, building, etc.). Focus your scope to view the object.
- ☐ Lock down your telescope's motion controls to avoid movement.
- ☐ Loosen the screw locks on your finder scope's mounting bracket (see your telescope's manual), and then position the finder scope so the object that's centered in your scope also is centered in your finder.
- ☐ Lock your finder scope into position.
- ☐ For higher precision, replace the low-power eyepiece in your telescope with one that provides higher magnification, then refine the alignment.

refractor and a 12-inch Schmidt-Cassegrain. Am I happy? Yes. Am I satisfied? Not even close. I now dream of a 20-inch telescope. I think you get the idea.

Is "achromat" different from "apochromat"? What do the words mean?

Both terms refer to the lens systems used in refracting telescopes. An achromat is a two-lens system. Apochromats also may employ two lenses, but they're more likely to have three or four. The main difference between achromats and apochromats is the amount of what's called "excess" color you'll see on bright objects. Excess color is not a color that's been added to what you're viewing. Rather, it usually appears as a purple fringe on one edge of the object. Apochromats deliver an image essentially free of excess color.

Through an achromat, you'll see excess color on bright objects like Jupiter, Venus, and the Moon. Many observers can ignore the excess color. Apochromats always are more expensive than comparable achromats, and usually by a sizeable amount.

Michael E. Bakich *is an associate editor of* Astronomy. *If your question isn't addressed here, e-mail him at mbakich@astronomy.com.*

I've just purchased a new telescope, and am really excited to use it. What's the first thing I should do?

Read the operating manual several times, and set up your telescope *indoors* before you try to set it up outdoors at night. This will familiarize you with the location and operation of any switches, buttons, and levers. Knowing how to use your telescope before you head outdoors will enable you to use your observing time efficiently. This will be especially helpful for sessions such as the Messier marathon (locating all Messier objects in one evening).

Why are objects I view through my telescope upside-down?

Just before the light collected by your telescope's main lens or mirror enters the eyepiece, it's flipped (see "Let's talk optics," above), so you see an inverted image. A prism assembly (usually called an "image erector") will re-flip the image, but adding this accessory will cause some light to be lost. And regarding observing, the telescope's function is to deliver the maximum amount of an object's light to your eye, so you don't want to lose light from flipping the image. Besides, keep in mind there's no up or down in space, and with most objects, you won't even know they're upside-down.

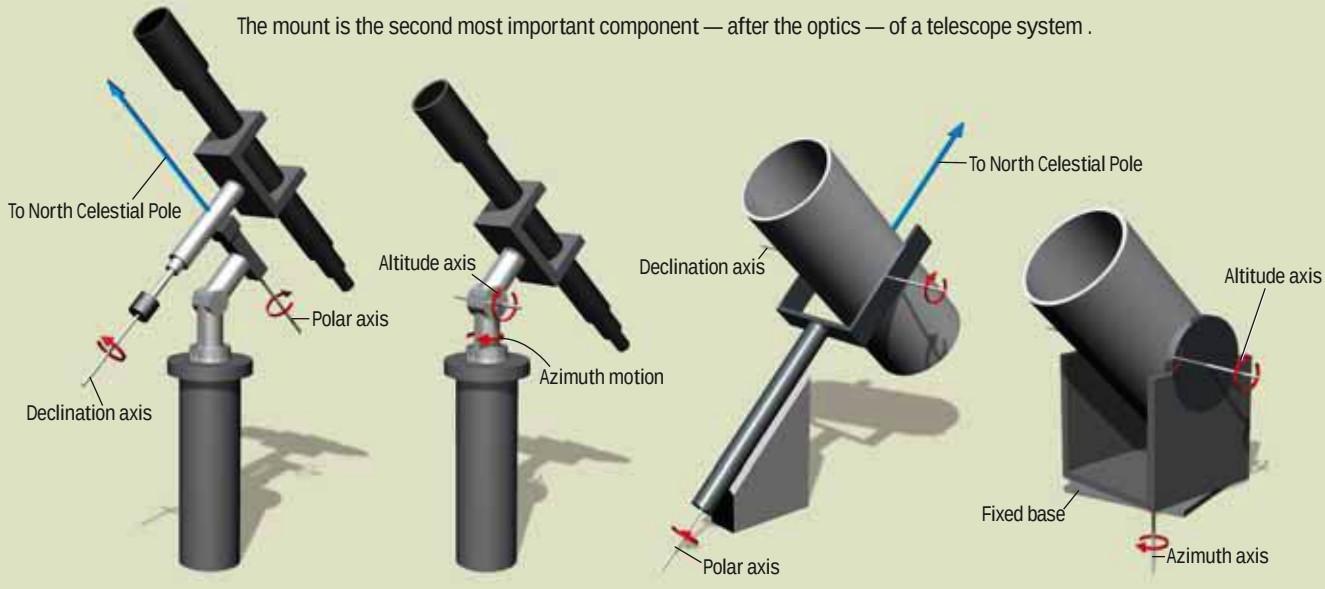
Can I use my telescope for views of earthly objects?

Absolutely! Many nighttime observers (usually those with small refractors because of size and portability issues) also use their telescopes for bird-watching or other nature-watching activities. Plus, think about pictures you've seen of sailors in centuries past — they almost always are at the bow looking through a telescope.

I would like to buy a telescope, but almost all I see are expensive. Why?

A good telescope is a combination of high-quality optics, machining, electronics, and mechanical controls. Such things aren't cheap. It takes incredibly expensive, high-precision machinery to grind the curves into mirrors or fabricate lenses. Some lenses comprise up to four separate elements,

The mount is the second most important component — after the optics — of a telescope system .



Equatorial mount

An equatorial mount moves in two planes, with one axis pointed toward the North Celestial Pole (NCP) — a spot in the northern sky near Polaris. With an optional motor drive, you can align the mount to the NCP, and the object you are observing will stay in the field of view. If you're planning to do long-exposure astrophotography or digital imaging, an equatorial mount is essential.

Altitude-Azimuth mount

An altitude-azimuth (alt-az) mount moves the telescope horizontal and vertical. A camera tripod is a good example of an alt-az mount.

Fork mount

It can be difficult to tell an alt-az fork mount from an equatorial fork mount. The difference is an equatorial fork mount lines up with the NCP. Fork mounts are popular with compound scopes. You will also find the majority of modern observatories use equatorial fork mounts.

Dobsonian mount

A dobsonian mount is an alt-az type specifically made for Newtonian reflecting telescopes. The mount, which employs a swivel base and a cradle assembly to hold the telescope tube, has a simple design and is easy to construct (if you choose to build one yourself). — *M.E.B.*

each with two optical surfaces. And the larger the mirror or lens, the bigger and stronger the supporting tube, drive, and tripod have to be.

12 Is there any way for me to "test-drive" a telescope?

Yes. Look in your area for an astronomy club, and visit one of its meetings. You'll find others who enjoy astronomy as much as you and are willing to share information and views through their telescopes. At one of the club's public or members-only stargazing sessions, you'll be able to look through many different telescopes in a short period of time.

13 Apart from quality optics, what's the most important thing in a telescope system?

The mount. You can buy the finest optics on the planet, but if you put them on an undersized or poor-quality mount, you won't be happy with your system. No telescope can function in high winds, but a poor mount will transfer vibrations in a light breeze. The mount's quality also affects the "damp-down" time. This is the interval between when you touch the scope (to focus, for example) and when the image in the eyepiece stops moving. Sturdy mounts reduce this to a second or 2. Bad mounts increase this time to an intolerable length. Mount quality is one more reason to "try before you buy."

14 Is a "go-to" scope better than one without go-to?

Yes. Once properly set up, a go-to scope (actually, it's the telescope's drive that's go-to) will save you lots of time by moving under internal computer control to any object you select. It's important, however, that you understand how to set up your scope, and that will require you to identify a few bright stars. Use a star chart (like the one found on page 55) to make this step easier. Even experienced observers prefer go-to scopes because they make star-hopping to deep-sky objects a thing of the past (when star-hopping, an observer locates a bright star and proceeds to ever-fainter stars until the target is located).

15 Since telescopes are used outside, do they need electricity?

No, but their motor (go-to) drives do. In most cases, telescope drives use direct current, which means you can either use batteries or obtain an adapter (usually you are given an option) that will allow you to plug into an electrical outlet.

Lighten up

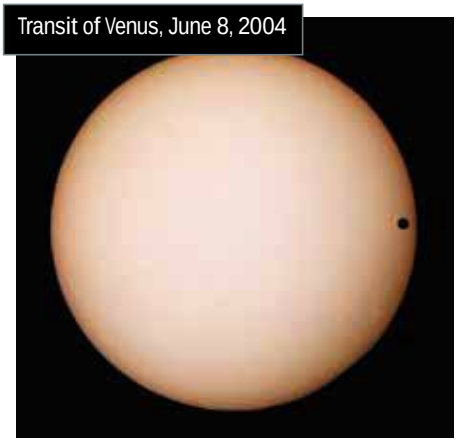
Always remember the best telescope for you is the one you'll use the most. If it takes an hour to set up a scope, or if your scope is large, heavy, and difficult to move, you may observe only a handful of times each year. If, on the other hand, your scope is quick to set up or if you can mount it permanently (or at least its tripod or pier), you may use it several times each week. A small telescope that's used a lot beats a big scope in a closet every time.

Meade's Deep Sky Imager slashes the cost of skyshooting and makes photographing the night sky a snap. /// BY MIKE MARCOTTE

Easy imaging for everyone

What if I said you could create images

like these your first night under the stars? Would you call me crazy? Read on …



Transit of Venus, June 8, 2004

GEORGE MOROMISATO

"I can't do this!"

Not so long ago, amateur astrophotography was reserved for those who had unlimited patience and deep pockets. Even after the introduction of a small silicon wafer called a charge-coupled device, or CCD, it seemed time, experience, and money were still keys to achieving satisfactory results when imaging celestial objects.

To top it off, anyone who was interested in trying astrophotography faced an array of costly CCD cameras and seemingly endless choices of image-capturing and processing software. Meade changed all that.

In 2003, Meade introduced the Lunar Planetary Imager (LPI). This easy-to-operate $150 CMOS camera (CMOS is the type of chip used — a complementary metal oxide semiconductor) introduced a simpler form of astroimaging to those who previously had been overwhelmed.

The LPI was limited to bright objects such as the Moon and planets. To fill the need for imaging deep-sky objects and to provide a camera capable of longer exposures, Meade recently introduced the Deep Sky Imager (DSI). Sound good? Here's a bonus: Its price tag is under $300.

M81 and M82

GEORGE MOROMISATO

Inside the DSI

Following its winning formula with the LPI, Meade designed the DSI in a compact, lightweight aluminum case. With a weight of only 10 ounces in a 3.25"-square by 1.25"-thick case, you can mount it directly on your telescope or your star diagonal with no counterweight.

The camera is controlled and powered by a single USB 2.0 computer connection, which eliminates the need for additional cords. Of course, if you intend to use your computer to control your telescope as well as the DSI, you will need additional cords.

The DSI's color CCD chip was designed by Sony and measures 510x492 pixels, totaling more than 250,000 pixels, and images are upsized to 640x480 when saved. Exposure times for the DSI can be as brief as $\frac{1}{10,000}$ of a second and as long as 1 hour. This range provides the latitude to image almost anything from bright lunar craters to faint galaxies.

The ease of *AutoStar*

The DSI comes with Meade's *AutoStar* Software Suite, which is the workhorse. The combination is a complete package so you don't need additional processing software.

If you've used the LPI, you'll recognize immediately the similarities and differences between its software and the new DSI software. The upgrade comes with an improved guiding capability along with a greater ability to manually control such functions as color quality, format options, and contrast settings.

The DSI records images in either the 8-bit or 16-bit mode. Eight-bit images contain 256 (2^8) shades of gray in each pixel of the three primary colors: red, green, and blue (RGB). Sixteen-bit images contain 65,536 (2^{16}) levels of gray.

The DSI's 8-bit formats are BMP, JPEG, GIF, and TIFF. JPEG is the default because JPEG images take up the least amount of hard-drive space. The software also provides 16-bit formats for FITS and FITS3 images.

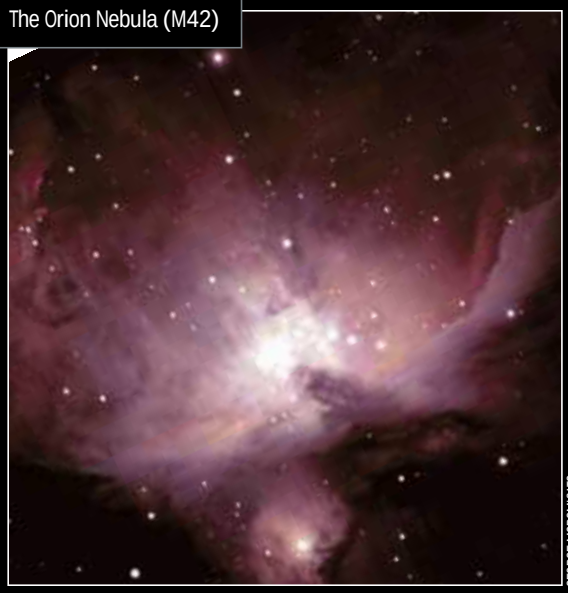
Users have the option to merge multiple images into a single picture, save them as

Mike Marcotte *is a retired firefighter who lives in — and now images from — El Paso, Texas.*

ASTRONOMY: WILLIAM ZUBACK

MEADE'S DEEP SKY IMAGER (DSI) allows you to capture celestial images at low cost. The DSI captured all the celestial images shown in this review.

The Orion Nebula (M42)



GEORGE MOROMISATO

The Pleiades (M45)

PETER W. O'BRIEN

The Orion Nebula (M42)

PETER W. O'BRIEN

Solar prominence, January 18, 2005

JACK NEWTON

Globular cluster M13

JACK NEWTON

Spiral galaxy M81

PETER W. O'BRIEN

The Moon, 21-image composite, January 2005

PETER W. O'BRIEN

uncombined images, or build up an image by progressively combining all previous exposures. This gives options for beginners and experienced astrophotographers. The software provides automated settings to adjust for the subject, whether it is a deep-sky object, the Moon, or a planet.

Although the software offers manual control over all functions and settings, it still provides a variety of automated processes for setting the exposure time and the desired color and contrast. These automated functions are where Meade excels at bringing astrophotography to the beginner.

At the same time, the software provides many features that an experienced astrophotographer will be able to use for fine-tuning images or creating special effects, such as time-lapse images.

The DSI can take any number of images separated by a user-specified time. This will provide a series of photos so the user can set up an image collage, say, of the phases of a lunar eclipse or a transit.

The software also supports creating animations, such as Jupiter's rotation.

Typical astronomical imaging requires certain procedures, and AutoStar has simplified most of them. For example, astrophotographers take several "dark frames" during an imaging session, average them, and then subtract the result from the final images. Basically, a dark frame is an image taken without allowing any light to reach the CCD chip. This identifies "hot pixels" (those that are "on" always) on the chip, so they can be matched and subtracted from a normally exposed image.

Meade, on the other hand, provides a menu-driven process that requires you to set only a couple of time parameters. The software then creates a dark-frame file, which will be subtracted from each image as it's captured and before it's saved. Because this is done before processing, it increases the accuracy of identifying hot pixels and results in a cleaner image.

THE COLOR IMAGING CCD CHIP (the square within the circle at left) is the DSI's heart. A 1¼" adapter (above) allows you to connect the DSI to a telescope like an eyepiece.
ASTRONOMY: WILLIAM ZUBACK

Learning the ropes

As with all new equipment, there is a learning curve. Meade's automation lessens some of this curve, but you'll have the best experience if you take the time to read and understand the DSI's instructions and functions. I learned this as I began to use the parfocal ring provided with the DSI.

Because the imager replaces the telescope's eyepiece, you focus by viewing the live image on the DSI capture screen, which is displayed on your computer. It can be tricky and time-consuming, but you can minimize the time by setting an eyepiece — preferably one with a 25mm focal length — and the DSI to the same focus.

This should be done in daylight using a terrestrial object as a target. Then, when you go out at night to start imaging, you can use the parfocal eyepiece to focus the object before you switch to the DSI.

The DSI is similar to most astronomy equipment: It's a good idea to set it up and take it through trial runs in a comfortable environment during the day. This will save you frustration that the cold and dark tend to impose on the ill-prepared.

"On your first night"

I consider myself a beginning astrophotographer. In fact, the first real imaging I did was with the LPI I purchased 2 years ago. So, I was able to test Meade's claim that the DSI would enable beginning astroimagers to "shoot and process stunning deep-sky photographs of galaxies, nebulae, star clusters and planets their first night out."

Although my first experience was frustrating, this was not the DSI's fault. Most problems stemmed from my inexperience, and the cold and dark did impose some serious frustration.

Heavy light pollution seemed to make the software glitches I experienced worse than they were. The computer that had been working well all day suddenly did not recognize the DSI. This turned out to be a bad USB connection, which shut down the operation for the night. Subsequent nights were hampered severely by bad weather or bright moonlight, but I gained experience each night. So, I didn't get images the first night out, but I had fun learning the ropes.

A new era

What Meade has accomplished with the DSI (and the LPI before it) can be compared to what Kodak accomplished with the Brownie camera in the early 1900s and the Instamatic camera in the early 1960s. Kodak introduced us to the term *snapshot*, a photo of life as it happened — not a staged professional portrait, but a record of a personal moment. Meade has put snapshots into astrophotography.

/// PRODUCT SPECIFICATIONS

MEADE DEEP SKY IMAGER

CCD chip: High-sensitivity Sony Super HAD color CCD sensor

Pixels: 510x492

Pixel size: 9.6 microns wide by 7.5 microns high

Image depth: 8-bit or 16-bit

Color depth: 48-bit color

Exposure range: $\frac{1}{10,000}$-second to 1 hour

USB compatibility: 2.0 and 1.1

Size: 3.25" by 3.25" by 1.25"

Weight: 10 ounces

Price: $299

Contact information
Meade Instruments Corporation
6001 Oak Canyon
Irvine, CA 92618
[t] 800.626.3233 (United States only)
[t] 949.451.1450
[w] www.meade.com

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We started ***astronomics*** over 25 years ago because we loved astronomy, not just as a business. Our sales may have grown over a thousand-fold since that first year, but we're still the same family-owned, family-run, full-line telescope dealer we were in 1979. And we still love astronomy.

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Meade LX200GPS telescopes have a GPS system to align your telescope on the sky *automatically*. You start observing in mere minutes.

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Built-in Smart Mount Technology improv s your LX200's poi t g accuracy as you observe. A Lunar Planetary Imager takes digital color pictures for you. Optional UHTC optics increase the light transmission by ¼n average of 15%s

Here are the Meade LX200GPS telescopes that we ship from our stock via Fedex ground:

7" Maksutov-Cassegrain **$2695**00
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8" Schmidt-Cassegrain **2195**00
8" Schmidt-Cassegrain, w/UHTC **2370**00
10" Schmidt-Cassegrain **2745**00
10" Schmidt-Ca segrai w/UHTC **2980**00

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A few touches on the Autostar computer of your LXD-75 speeds you to any of more than 30,000 stars, planets, and deep space objects, then tracks it accurately for as long as you want to observe. You spend more of your time actually looking *at* celestial objects and less time looking *for* them with a Meade LXD75.

Each has an adjustable height steel leg tripod, battery-operated dual motors, finderscope, eyepiece, illuminated polar finder, Autostar computer, and a Lunar Planetary Imager color digital camera.

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The **Meade** 10" through 16" modified Ritchey-2 rétien telescopes put virtually the same premium optical design used in the Hubble Space Telescope into affordable and portable telescopes for amateur astronomers. it aNwide coma-free field for astrophotography, Ritchey-Chrétiens are the telescope of choice in many professional observatories.

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The 1 **'RCX400 16"** **15,999**00

Each adds a full aperture correcting lens to the R-C design that re uce öesidual astigmatism so stars stay point-like across the entire field. Level North Technology and GPS make aligning on the sky *automatic*. You start observing in minutes. Standard equipment UHTC optics fo a 15% increase in light transmission, High Precision Pointing, Permanent Periodic Error Correction, a 2" UHTC star diagonal, and a 2" 24mm Ultra Wide eyepiece – the l s of features just goes on and on.

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Meade Deep Sky Imager (DSI) for $299.

The **Meade Deep Sky Imager** takes color deep sky ohotos at a fraction the cost of a CCD camera. Use it with any scope to take photos of galaxies, nebulas, star clusters – plus the Moon and planets.

The easy-to-use Meade Deep Sky Imager also includes the Autostar Software Suite of planetarium and imaging control software in its low price of only $299.

A Premier ETX is almost as easy as GPS!

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Each new Premier Series **Meade ETX** 3.5" to 5" Maksutov-Cassegrain has *Level North Technology* to make it easy to align your scope on the sky.

Simply tell the ETX your zip code or location. It levels its optical tube (a full color deep space image decorates the tube), finds North, sets the time, and moves to its alignment stars – *all automatically!* Center the new wide-field red dot finder on the alignment stars and start observing. That's all it takes. Using an ETX is almost as easy as using a GPS system, but a new ETX Premier costs a lot less!

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A best-selling 80mm semi-apo for only $399.

$399
William Optics ZenithStar 80mm semi-apo optical tube

The **William Optics ZenithStar 80** is such a great value that we have trouble keeping it in stock. Some dealers might say that and be telling you a story, but it's true with us. We get these scopes in 20 at a time and ship them out to waiting customers almost immediately.

The ZenithStar 80 semi-apochromatic doublet costs only **$399**. It has an 80mm multicoated f/6 optical system with a fully rotatable 2" Crayford-style focuser, a 1.25" eyepiece adapter, retractable self-storing lens shade, dust caps, and a fitted soft carry bag. It also has a removable L-shaped mounting shoe that will mount on either a photo tripod or on a Schmidt-Cassegrain piggyback. It can be used as a super finder for your main scope or as a quality second scope for spur-of-the-moment astronomy, travel, or birding.

Get a $40 gift certificate with this focuser and diagonal.

Some manufacturers charge as much as $250 for a 2" star diagonal with a 97% reflectivity enhanced aluminum 1/10th wave mirror and a 1.25" eyepiece adapter. But the **William Optics** *silver-coated* 2" diagonal, our #W2, is only **$130**!

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A super deal is our limited availability special that combines the 2" diagonal and SCT focuser above. Buy them together at their regular **$279** total price (our #WDSKIT) and you get an ***astronomics*** $40 gift certificate to use on any later purchase.

A bird in the hand looks great, if that bird is a Swan.

These Swans won't ruffle your feathers. They're the economical new Swan wide field eyepieces from **William Optics**.

The 1.25" Swans (9, 15, and 20mm) are $78 each. Each has a wide 72° field and sharp images. Equally sharp are the 2" Swans (25, 33, and 40mm) at $118 each. They also have a wide 72° field (70° on the 40mm).

They may be called Swan eyepieces after the swan logo on all William Optics products, but that's no reason to duck these great eyepiece values.

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Some best sellers from Burgess Optical . . .

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Other binocular viewers can cost over $1200, but the **Burgess Optical** binoviewer costs only $199, *including* a pair of fully-multicoated 65° field 17mm eyepieces. It has multicoated 22mm clear aperture BaK-4 prisms to make your eyes happy, and a sensationally low price that will make your wallet happy, too.

Designing a binoviewer isn't rocket science, and computerized manufacturing makes it easy to make it good and make it inexpensive. We've already sold over 200 of these to very happy buyers. Try one for yourself and see.

$199

Wide field eyepieces for only $49.

Burgess Optical 1.25" wide angle eyepieces are very good performers at a remarkably low $49 price. Their sensible price makes them an obvious choice for binocular viewers. Available in a 60° field 8mm or 12mm, a 65° field 17mm, and a 67° field 20mm.

A big 65mm ED astro binocular for only $295.

This 22 x 65mm binocular (designed by renowned refractor creator Thomas M. Back) uses costly low dispersion FPL53 ED glass for a wide 3.5° field virtually free of spurious color. From **Burgess Optical** and **William Optics**, this **TMB**-designed bino is the best astronomical binocular value around. Period.

$295

A $799 4" ED scope that's only 13½" long.

$799

The SD101 Backpacker from **Burgess Optical** uses a 4" ED (extra low dispersion) glass f/5.5 doublet lens for color correction that's eight times better than a typical achromat. Add its superb mechanics and you have a top-quality and very compact refractor at a rock-bottom price.

The Backpacker comes very fully equipped with CNC-machined tube rings, a retractable lens shade, a 2" rotating Crayford focuser, a 2" *dielectric* star diagonal with 99% reflectivity and a 1.25" eyepiece adapter. A 38mm Super Wide 2" eyepiece with a full 70° field, and a fitted backpack carrying case.

Compare the SD101 with any 4" scope. Quality optics, extreme portability, and an amazingly low price make this wide field ED scope an easy choice for anyone who wants a great all-around or travel scope at a truly affordable price.

Are these prices great? You bet they are.

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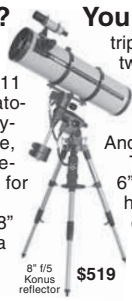
3.5" f/11 Konus refractor

The prices on these **Konus** telescopes are downright amazing. Consider the 90mm **Konusmotor-90** f/11 refractor, left. It has a good equatorial mount with a battery-operated motor drive, *two* 1.25" Plössl eyepieces, and more – for only $209!

The **Konusky-200** 8" f/5 reflector, right, has a heavy duty equatorial mount with a steel leg tripod, *dual-axis* drives, two good 1.25" Plössl eyepieces, 8 x 50mm finderscope, a polar axis finder, and more. And it's only $519!


$519

8" f/5 Konus reflector

The **Motormax-150** 6" Maksutov, right, has the same heavy duty mount and accessories as the 8" reflector – but at a $799 price that's well below that of other Maks.

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6" f/12 Konus Maksutov

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You don't need to know Alkaid from Algol to align a **Celestron CPC** scope on the sky. Just point a CPC at any three of the 50 brightest lights in the sky (3 stars, or 2 stars and a planet, but no UFOs or moving airplanes), and the CPC will find over 45,000 deep space objects for you at the touch of a button.

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Celestron CPC Schmidt-Cassegrains are available in the following sizes:

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11" **CPC1100**, Starbright coatings . **2599.00**
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Each has a GPS system and all the visual and photographic features you want and need, plus Celestron's best multi-coated optics ever.

Celestron 11" scopes start at only $1699.

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With almost twice the light-gathering of an 8" scope, **Celestron Advanced Series** 11" German equatorial mount Schmidt-Cassegrains show you more deep space wonders than an 8" SCT on a fork mount – *for about the same price.*

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C11S with XLT coatings **1979.00**
C11S-GT go-to German equatorial **1999.00**
C11S-GT go-to with XLT coatings **2279.00**

The C11S and C11S (XLT) have a heavy-duty equatorial mount, adjustable height tripod with 2" steel legs, slow motion controls, setting circles, a 40mm Plössl eyepiece, and a 9 x 50mm finder. Starbright multicoated optics are standard on the C11S. XLT multicoatings on the C11S (XLT) give you 16% more light. An optional dual-axis drive is available.

The C11S-GT and C11S-GT (XLT) go-to models add dual motors and a NexStar computer that automatically finds over 45,000 stars and objects for you.

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Celestron captures the solar system for $99.

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There is a true color CCD camera in the **Celestron NexImage** Solar System Imager. It's a Sony HAD (Hole Accumulation Diode) full color 640 x 480 CCD with 5.4 micron pixels.

The NexImage takes high power lunar and planetary images with any telescope and sends them to your computer view live or print out later. At only $99, it makes solar system imaging affordable for veryone.

Economical no-guesswork Celestron SLT go-to scopes.

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80mm Celestron NexStar 80 SLT

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NexStar 102, 102mm refractor **419.00**
NexStar 114, 114mm reflector **379.00**
NexStar 130, 130mm reflector **399.00**

Each is complete with two eyepieces, a Star Pointer red dot finder, motor drives, stainless steel tripod, NexStar computer, software to control the scope from your home computer, and more.

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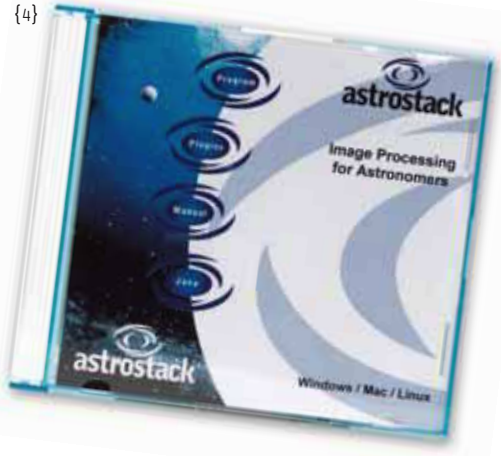

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2. Meade CaptureView Binoculars

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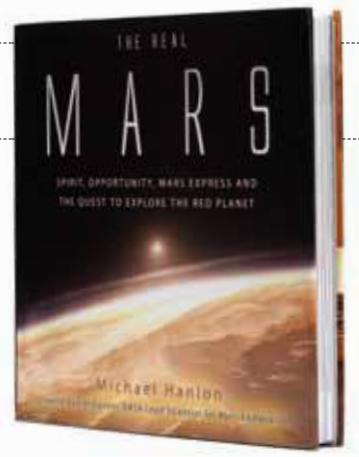


Earthlings in search of a real Mars

The Real Mars
Michael Hanlon, 250 pages, Carroll & Graf Publishers, 2004; hardcover, $35

In *The Real Mars*, Michael Hanlon presents a complicated science story with clarity and even wit. Readers should take the title somewhat tongue-in-cheek. Hanlon shows clearly how much "the real Mars" — as viewed by culture and science alike — has often been built from equal parts of human desire and groupthink, with the science being influenced strongly by both.

Hanlon's early chapters ease the reader into martian exploration through the twin lenses of Percival Lowell and pop culture. Lowell's observations of non-existent engineered channels on the Red Planet make a cautionary tale. When it comes to Mars, Hanlon says, both scientists and ordinary people have proven highly suggestible.

The question of water on Mars opens a door into the martian past, and Hanlon uses it to explore several themes, including the chances that a once-wet martian "Eden" dried up or went underground. Hanlon also does justice to the alternative "White Mars" hypothesis, in which carbon dioxide instead of water is the agent creating fluid-formed surface features.

The author then launches into the history of Mars exploration by spacecraft. Some engineers dreamed big: In the late 1940s, Wernher von Braun envisioned a fleet of 10 huge manned spaceships. And by the late 1950s, planning was underway for Project Orion, which would propel rocket ships with atomic bombs.

But if political drives got humans to the Moon's surface, Mars has seen nothing but robotic probes. Hanlon spends two chapters — "Going to Mars" and "Not Going to Mars" — on plans for human exploration, past, present, and future.

Out of these efforts has arisen the current robotic missions to Mars. The successes of Mars Global Surveyor, Mars Odyssey, and the Mars Exploration Rovers fill the book's last chapters.

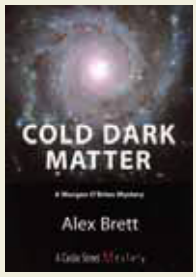
But losses have been more common than successes — less than half of all Mars-bound spacecraft arrive. Nonetheless, five missions are now at work, wonderfully revising our views of the planet.

Hanlon does a good job taking readers into the scientific, technical, and human-interest aspects of these missions. In particular, he — a Brit — relates well the story of the loss of the British lander, Beagle 2, in December 2003.

The Real Mars is full of excellent photographs and drawings. Even the title spread showcases a panorama of Bonneville Crater taken by Mars rover Spirit. Yet as an ordinary reader and as a Mars scientist, I would have enjoyed seeing more information about the images.

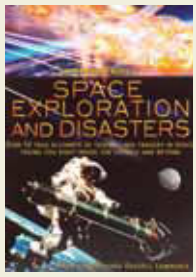
In any case, this book presents a great blend of accessible scientific and technological explanations with an accurate vision of the spirit of exploration.

— DEVON BURR *studies what water has done to the martian surface. She has been a research geologist at the USGS in Flagstaff, Arizona, and currently works at the SETI Institute in Mountain View, California.*



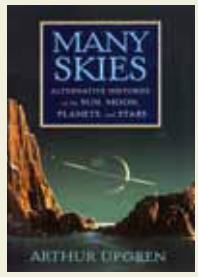
Cold Dark Matter
Alex Brett, 348 pages, Dundurn Press, 2004; paperback, $10.99

Scientific fraud begets murder in this mystery novel set in Ottawa and on Mauna Kea at the "Franco-Canadian Telescope." Call it cloudy-night reading for astronomers.



The Mammoth Book of Space Exploration and Disasters
Richard Russell Lawrence, editor, 495 pages, Carroll & Graf, 2005; paperback, $13.95

Astronauts, test pilots, and space engineers tell their experiences in 50 true stories of space exploration from books, newspapers, and interviews. The locales vary from a Florida launch pad to the lunar surface. The editor's linking descriptions provide context.



Many Skies
Arthur Upgren, 199 pages, Rutgers University Press, 2005; hardcover, $24.95

What if the Sun had formed within a star cluster? Or if Earth had three Moons — or rings? What if Earth were the Sun's sole planet? Upgren explores such "alternative histories" and tells how they would change us and astronomy.

Observing Variable Stars, Novae and Supernovae
Gerald North, 230 pages, Cambridge University Press, 2004; hardcover, $45

North gets readers started on variable stars, covering telescope collimation, types of variable stars, and estimating brightness visually and with CCD imagers. A CD-ROM (included) has finder charts and light-curves.

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-Ralph Holt / RB-66 and NGT-12.5 owner

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- Paul Carmody / RB-66 owner who traded up to an RB-10

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RESOURCES

Learn more about this issue's topics:

THE HOT, VIOLENT WORLD OF GALAXY CLUSTERS

ARTICLE — Cambridge University's Andrew C. Fabian's technical review "Cooling Flows in Clusters of Galaxies" appeared in the 1994 volume of *Annual Reviews of Astronomy and Astrophysics*, beginning on page 277.

BOOKS — A good introduction to galaxies is *Galaxies and the Cosmic Frontier* by William H. Waller and Paul W. Hodge (Harvard University Press, 2003).

Looking for something more advanced? *Galaxies in the Universe: An Introduction* (Cambridge University Press, 2000), by Linda S. Sparke and John S. Gallagher III, has undergraduate astronomy and physics majors in mind.

WEB — The proceedings of a summer 2003 conference on cooling flows is available for downloading (PDF or PS files) at *www.astro.virginia.edu/coolflow/proc.php*. To save time, skim the abstracts of the talks at *www.astro.virginia.edu/coolflow/abs.php* first.

Visit *nedwww.ipac.caltech.edu/level5/index.html* for a general outline of extragalactic astronomy and cosmology.

NEIGHBORHOOD SECRETS

ARTICLES — Author Steve Nadis probed a related topic in "Second light" (*Astronomy*, January 2005). In it, he examined how the universe's first generation of stars — each of which contained up to several hundred times the Sun's mass and burned 20 times hotter and a million times brighter than our Sun — gave birth to the more normal second-generation stars we see in the halo of the Milky Way.

University of Texas astronomer Christopher Sneden and his colleagues reported on their measurements of the abundance of 57 elements in a Milky Way halo star in "The Extremely Metal-poor, Neutron Capture-rich Star CS 22892–052: A Comprehensive Abundance Analysis" (*Astrophysical Journal*, July 10, 2003).

Roger Cayrel of the Observatory of Paris-Meudon and his colleagues used the first discovery of uranium outside the solar system (in the star CS 31082–001) to derive an age of 12.5 billion years for the Milky Way Galaxy. The team reported its findings in "Measurement of stellar age from uranium decay" (*Nature*, February 8, 2001).

CYCLE OF THE SUN

ARTICLES — Analysis of the 3-D structure of sunspots revealed by the Swedish Solar Telescope on the Canary Islands appeared in the May 2004 issue of *Solar Physics*.

Nat Gopalswamy of NASA's Goddard Space Flight Center reported the relationship between the Sun's polarity flip and the cessation of high-latitude coronal mass ejections in the November 20, 2004, *Astrophysical Journal Letters*.

Mausumi Dikpati and her High Altitude Observatory group reported their work replicating solar cycle 23 in the February 1, 2004 *Astrophysical Journal*.

David Hathaway of NASA's Marshall Space Flight Center and his colleagues report evidence that a deep meridional counterflow times the sunspot cycle in the May 20, 2003 *Astrophysical Journal*.

WEB — For high-resolution solar images and time-lapse movies, visit the Swedish Institute for Solar Physics web site at *www.solarphysics.kva.se*.

CATCH A CARNIVAL OF GALAXIES

BOOKS — Look for Edwin Hubble's *The Realm of the Nebulae* (Yale University Press, 1936), which has been reprinted often and still is available.

Allan Sandage assembled dozens of beautiful photos in the *Hubble Atlas of Galaxies* (Carnegie Institution of Washington, 1961) to provide a pictorial guide to the Hubble classification scheme.

Galaxies by Tim Ferris (Abrams, 1980) functions almost as a color Hubble atlas, although it was not intended as a systematic illustration of the classification.

Sidney van den Bergh created an interesting guide in *Galaxy Morphology and Classification* (Cambridge University Press, 1997). While aimed at professional astronomers, any curious backyard astronomer will find it fascinating.

WEB — Hubble's famous galaxy classification first appeared in *The Astrophysical Journal* in 1926. The classic paper is available at NASA's Astrophysics Data System at *adsabs.harvard.edu/bib_abs.html*. In the Reference Query box, type in "Hubble 1926 ApJ," then click "Send Query." Of the two papers this retrieves, you want "Extragalactic nebulae." Download the paper by clicking on the "F" link in the first line of the citation. Caution: It's 52 pages long and 3.8 MB in PDF format.

Astronomer William Keel discusses the different systems used to classify galaxies at *www.astr.ua.edu/keel/galaxies/classify.html*.

ASK ASTRO

ARTICLE — A team led by Liming Li of Caltech published an analysis of spots found in Jupiter's atmosphere as Cassini cruised past. The team's report, "Life cycle of spots on Jupiter from Cassini images," appeared in the November 2004 issue of *Icarus*.

WEB — The gravitational redshift plot is adapted from the work of Sweden's Lund Observatory. One version appears in "Wavelength shifts in solar-type spectra," which is available at *www.astro.lu.se/~dainis/Papers/astro-ph_0409212.pdf*.

TELESCOPES 101

ARTICLE — Michael Bakich's "The backyard telescope" (*Astronomy*, November 2004) is a great introduction to the history of amateur astronomy and telescopes.

WEB — For a list of objects to observe with your new telescope, see Bakich's "Using a telescope" at *www.astronomy.com/asy/default.aspx?c=ss&id=10*. Also, be sure to check out "An introduction to the deep sky," at *www.astronomy.com/asy/default.aspx?c=a&id=2229*.

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A full 8" (203mm, f/4.9) parabolic primary mirror, which gathers 73% more light than a 6". The tube features a 2" aluminum rack-and-pinion focuser and a sturdy 4-vane holder. Includes 6x30 finder scope, two 1.25" Sirius Plössl eyepieces (25mm and 10mm), collimation cap and dust-cap.

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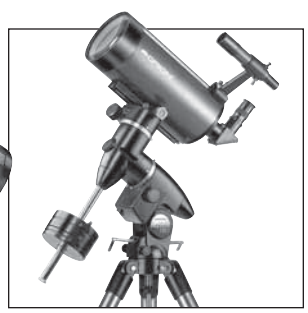

SkyView Pro 127 EQ

The 5" Maksutov-Cassegrain optics offer great views of deep-sky gems. And its long focal length of 1540mm (f/12.1) is great for high-magnification study of the Moon and planets. Includes 6x30 finder scope, two 1.25" Sirius Plössl eyepieces, 90° mirror star diagonal, optical tube carry case and dust-cap.

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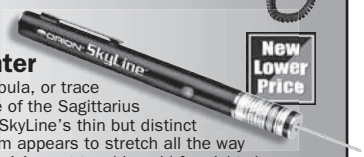

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JUNE 4–11, 2005

The Grand Canyon Star Party offers

amateur astronomers a rare opportunity: observing the night sky with others at one of the United States' premiere national parks. ❨ For more than a decade, amateur astronomers have set up their telescopes at the canyon's north and south

DEAN KETELSEN

THE GRAND CANYON serves as a breathtaking backdrop for displays, solar observing, and other daytime activities during the Grand Canyon Star Party.

rims for the star party. It's a friendly gathering, and attendees readily share their views with tourists casually hiking through the park.

Great viewing is ensured by the canyon's elevation and remote location, which make the skies the darkest in the area.

During the daytime, take in the scenery on a hike or bicycle ride, or make the short trip to Lowell Observatory or Meteor Crater. Monument Valley, the Painted Desert, and Flagstaff are a short drive away.

Don't delay in registering — spots for this event fill up fast. Just like previous years, there is no registration fee for the star party. However, the National Park Service charges $20 for entry into the site. Camping is not permitted at the observing site.

Astronomy assistant editor Liz Kruesi will attend.

For more information, call Dean Ketelsen at 520.293.2855; e-mail, ketelsen@as.arizona.edu; web site, *www.tucsonastronomy.org/gcsp.html*.

JUNE 2–5

Almost Heaven Star Party

The Mountain Institute, Spruce Knob, West Virginia. The Northern Virginia Astronomy Club and the Virginia Outdoor Lighting Taskforce will host this first annual event. Register on NOVAC's site beforehand — there will not be any on-site registration. For more information, visit *www.novac.com*.

JUNE 2–5

Wisconsin Observers Weekend

Hartman Creek State Park, Waupaca, Wisconsin. Hosted by the Northeast Wisconsin Stargazers, all five group campsites are reserved, limiting light-pollution intrusion from other campers in the park. For more information, visit *www.newstar.org/wow*.

JUNE 3–6

Jersey Starquest

Hope Conference Center, Hope, New

Jersey. This event will feature lectures, workshops, exhibits, a deep-sky challenge, and door prizes for adults and children. For more information, visit *www.princetonastronomy.org*.

JUNE 3–6

North Dakota Star Party

Cross Ranch State Park, near Hensler, North Dakota. This gathering is the year's first major — and largest — star party in North Dakota. Activities include observing, lectures, and workshops. For more information, e-mail Chris at ndsp05@hotmail.com; web site, *www.und.edu/org/nsas*.

JUNE 4

Central Texas Stars and Guitars Fest

Lake Whitney State Park, near Whitney, Texas. This day-long event will feature great observing under dark skies, as well as a music jamboree and recreational activities at the state park. For more information, visit *www.whitney-astro.com*.

JUNE 10

Apollo Rendezvous

Boonshoft Museum of Discovery, Dayton, Ohio. Hosted by the Miami Valley Astronomical Society, this year's theme is "Astronomy Outreach." The gathering will feature speakers, astrophotography workshops, vendors, and door prizes. For more information, visit *www.mvas.org*.

JUNE 11

Stars Over Clarkston

Clintonwood Park, Clarkston, Michigan. The event begins with solar observing, followed by a concert. After the musical performance, there will be astronomy lectures and observing. For more information, e-mail Vince Chrisman at vchrisman1@comcast.net; web site, *www.warrenastronomicalsociety.org*.

JUNE 30–JULY 4

Stargazing Manitoulin

Gordon's Park, Manitoulin Island, Ontario. The site offers stargazing under the darkest skies in the area. Besides the typical star-party fare, attendees will be treated to nature activities. For more information, visit *www.gordonspark.com*.

JULY 1–4

Island Star Party

The Victoria Fish and Game Association site, near Victoria, British Columbia. Hosted by the Cowichan Valley Star-Finders, this event features observing, lectures, and guided nature walks. For more information, visit *starfinders.cvnet.net/home.htm*.

JULY 6–11

Shingletown Star Party

Shingletown Airport, Shingletown, California. Each year, seasoned veterans and novices of astronomy gather on the Shingletown Airport's runway for observing. Attendees also will find lectures, workshops, and vendors at this star party. For more information, visit *www.shingletownstarparty.org*.

JULY 7–10

Rocky Mountain Star Stare

Pike National Forest, near Colorado Springs, Colorado. This event is sponsored by the Colorado Springs Astronomical Society. The high elevation will provide incredible views at night. Workshops, lectures, and contests will be held during the day. For more information, visit *www.rmss.org*.

JULY 24–AUGUST 13

International Astronomical Youth Camp

Závadka nad Hronom, Slovak Republic. This camp is a program for English-speaking students ages 16 to 24 who are interested in astronomy. For more information, visit *www.iayc.org*.

CONTACT INFORMATION

Please submit club announcements 4 months in advance to Coming Events, *Astronomy*, P.O. Box 1612, Waukesha, WI 53187, or jmcgovern@astronomy.com. Also use this e-mail address to submit your events for our on-line calendar.

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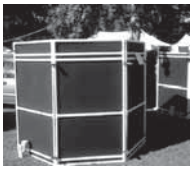

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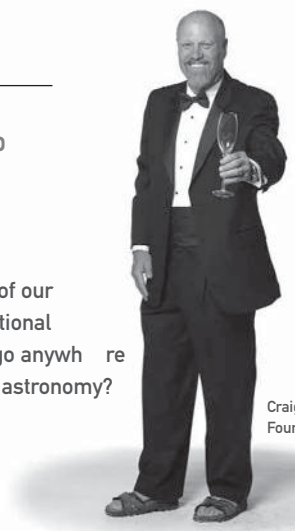

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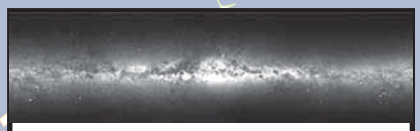
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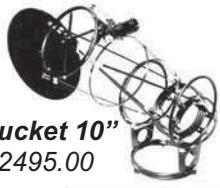
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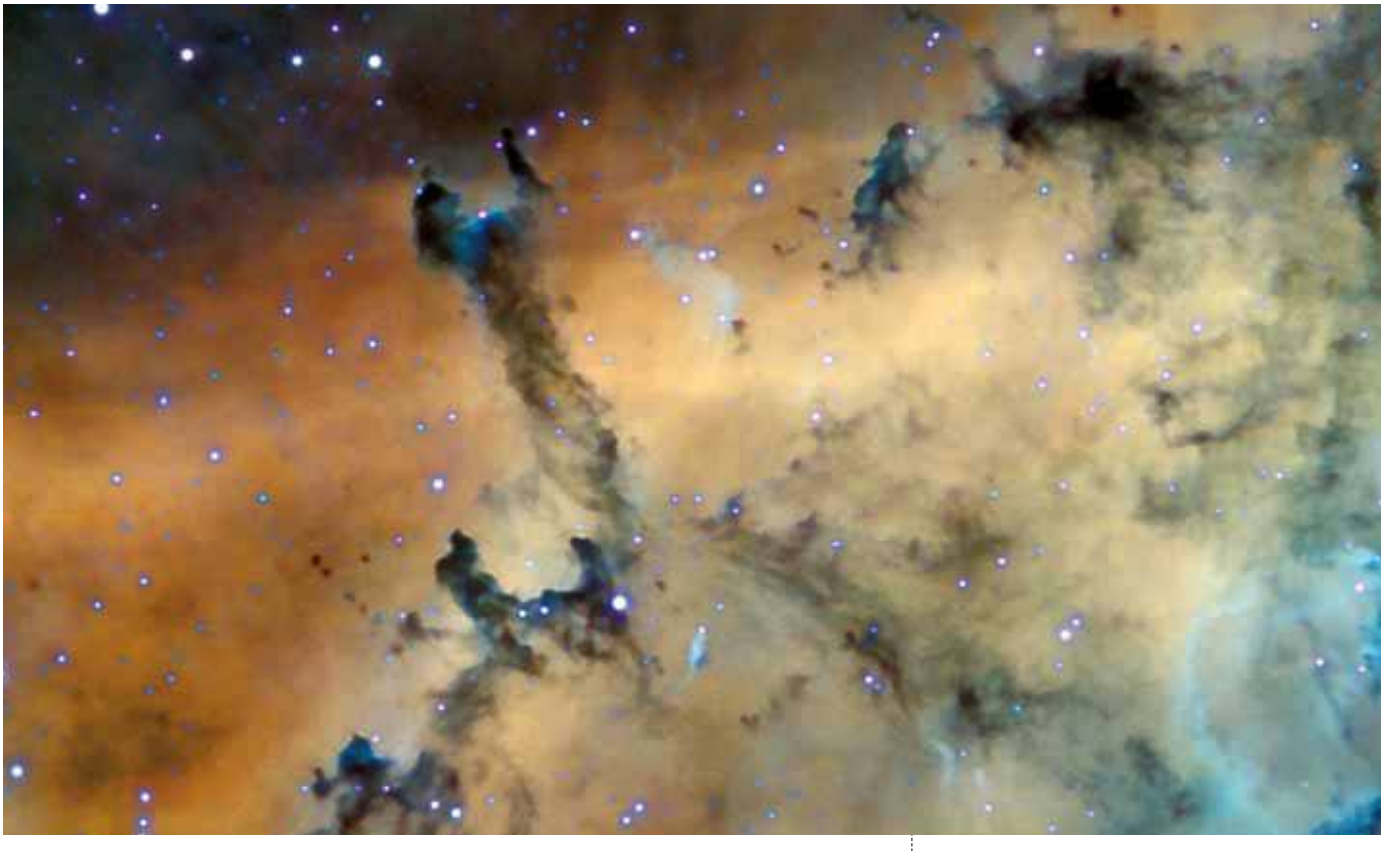

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THE ROSETTE NEBULA (NGC 2237–9) (20-inch RC Optical Systems Ritchey-Chrétien reflector, SBIG ST-10XME CCD camera, four-channel image using a Silicon II, a Hydrogen-alpha (Hα), and an Oxygen III filter as the RGB channels; some Hα data served as a fourth channel; 60-minute exposures were taken through the SiII and OIII filters, and a 120-minute exposure was taken through the Hα filter) /// KEN CRAWFORD

Top left, REFLECTION NEBULA NGC 1333 IN PERSEUS (12½-inch Optical Guidance Systems Ritchey-Chrétien telescope at f/5.7, SBIG ST-10XE CCD camera, LRGB image with exposures of 105, 15, 15, and 25 minutes, respectively) /// TED WOLFE

Top right, THE OWL CLUSTER (NGC 457) IN CASSIOPEIA (8-inch Intes Micro MN86 Maksutov-Newtonian telescope at f/6, SBIG ST-2000XM CCD camera, RGB image with exposures of 18, 18, and 27 minutes, respectively) /// DEAN SALMAN

Bottom, DESERT MOONSET (Olympus OM-1 35mm camera, 200mm lens at f/8, Fuji Provia 100F slide film, 1/60-second exposure taken November 27, 2004, at 7:13 A.M. MST from Saguaro National Monument, Tucson, Arizona) /// JOE ORMAN

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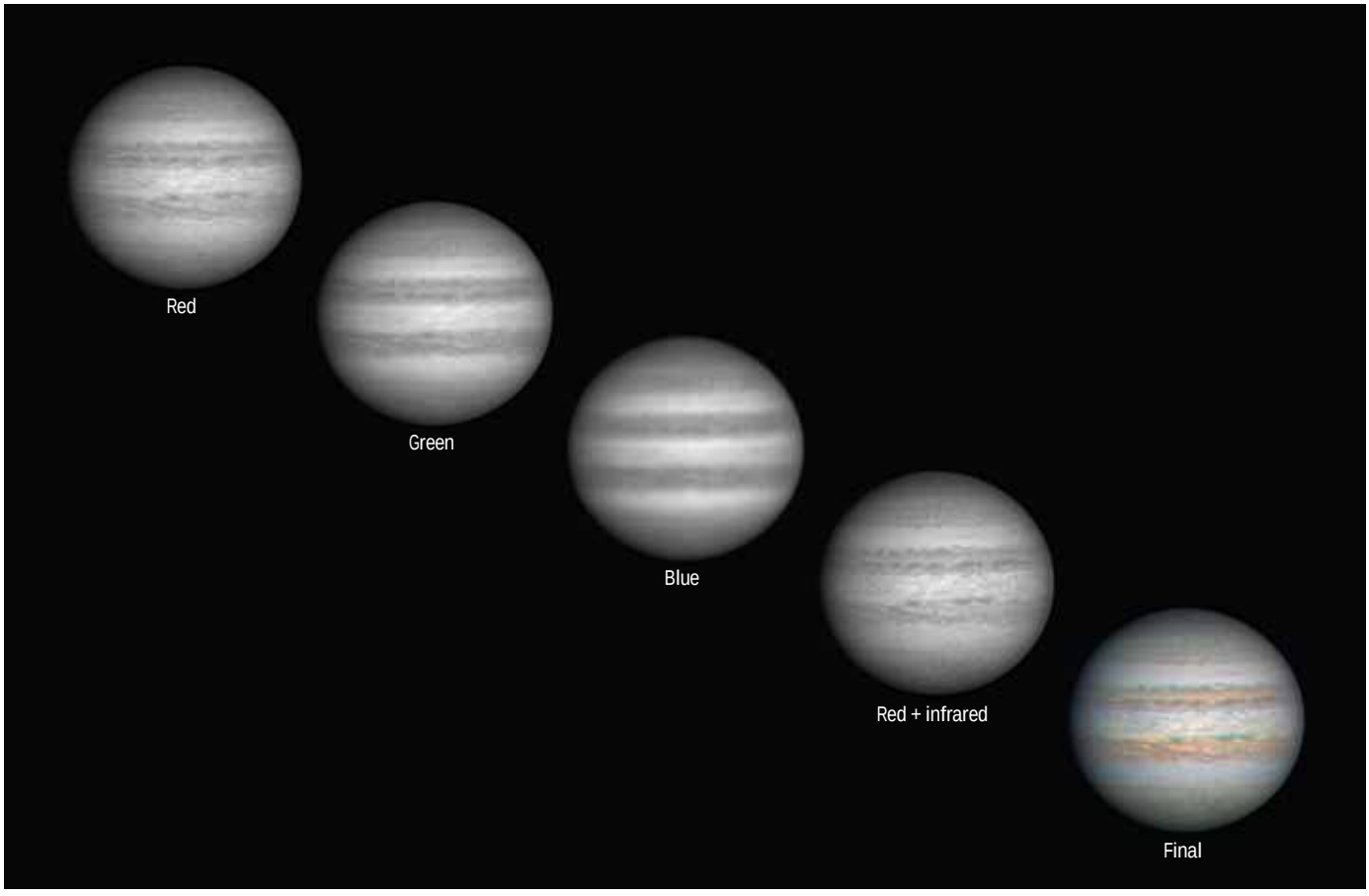

Top, IMAGING JUPITER (10-inch Planewton DL252 telescope, Lumenera LU075M camera, RRGB image with the best 600 of 2,160 1/18-second frames stacked in each color, taken January 8, 2005, from Mt. Labro, Italy) /// PAOLO LAZZAROTTI

Bottom left, EMISSION NEBULA NGC 6820 (8-inch Celestron Schmidt-Cassegrain telescope at f/6.3, Starlight Xpress SXVH9 CCD camera, HαRGB image with exposures of 180, 15, 15, and 15 minutes, respectively) /// WOLFGANG PROMPER

Bottom right, PTOLEMAEUS AND ALPHONSUS (10-inch Orionoptics Newtonian reflector at f/4.8, Philips ToUcam PCVC740k webcam, mosaic of six 100-frame images, 1/25-second exposures, taken September 5, 2004) /// RALF VANDEBERG

SPIRAL GALAXY NGC 2997 IN ANTLIA (14½-inch RC Optical Systems Ritchey-Chrétien telescope, SBIG ST-10XE CCD camera, LRGB image with exposures of 120, 45, 45, and 75 minutes, respectively) /// DANIEL VERSCHATSE

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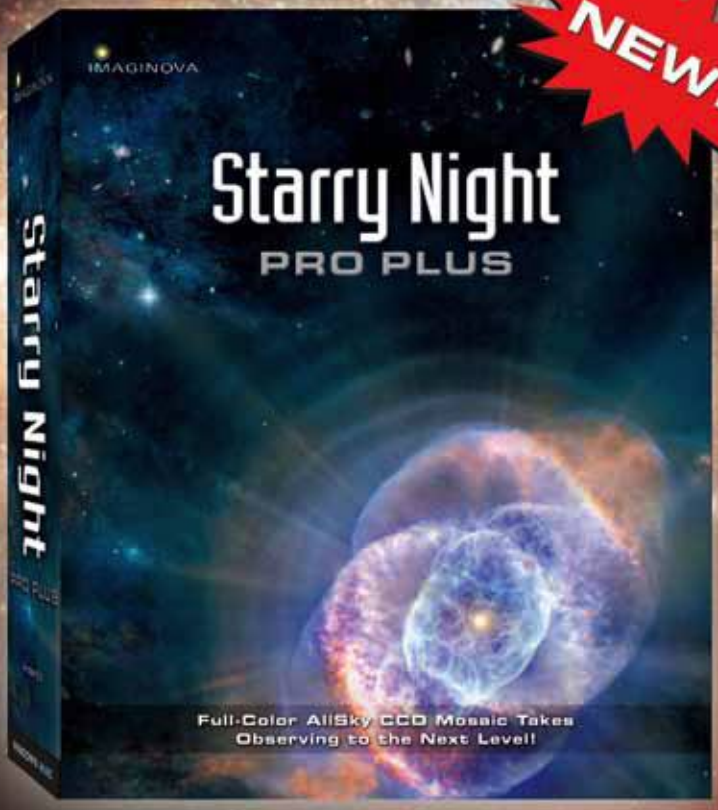

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